Understanding Hydronic Systems

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SPACE PAK HYDRONICS

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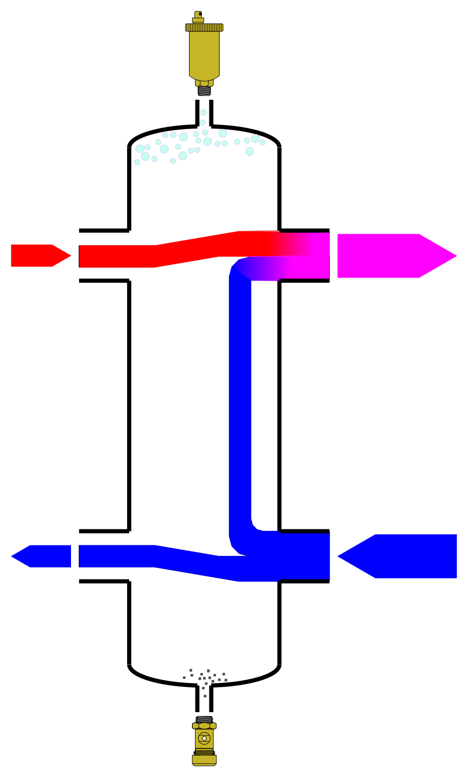
Presented by: John Siegenthaler, P.E.



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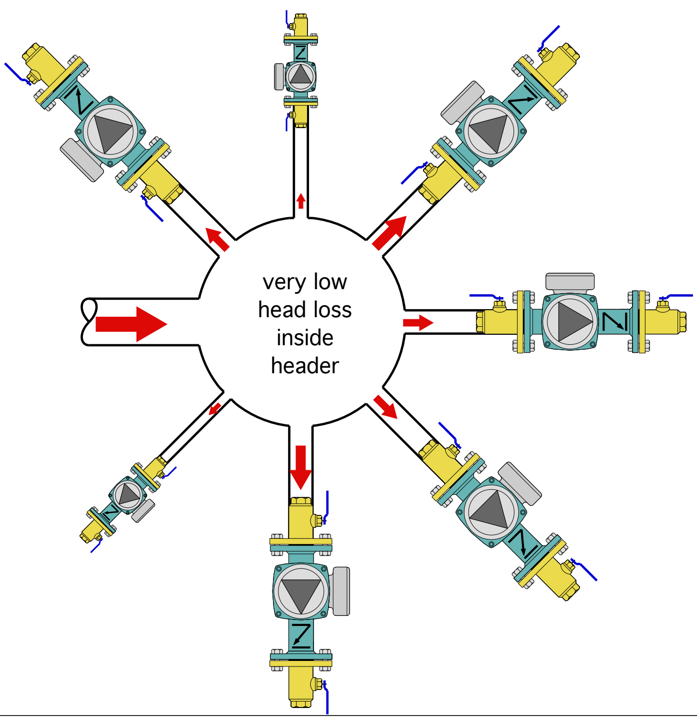
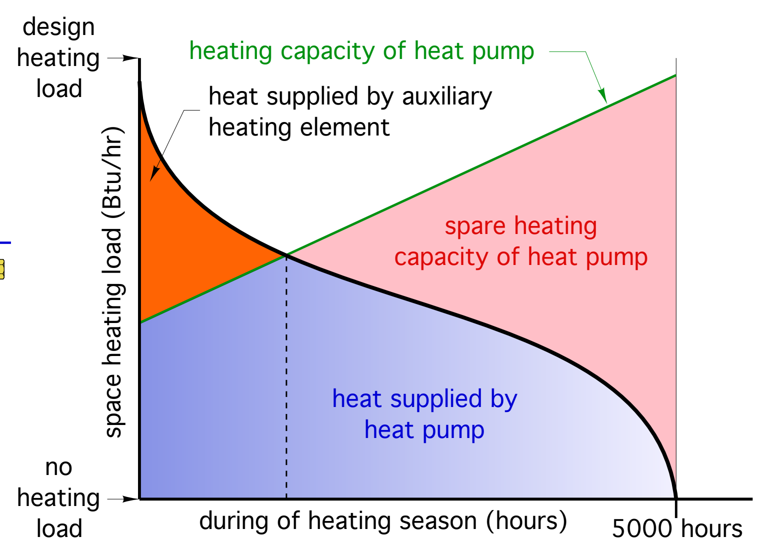
Understanding Hydronic Systems

Today's topics...

- Hydraulic separation, what is it? & Why it's important
- Distribution efficiency & low power pumping
- Air-to-water heat pump systems
- Low temperature hydronic heat emitters
- Small scale chilled water cooling





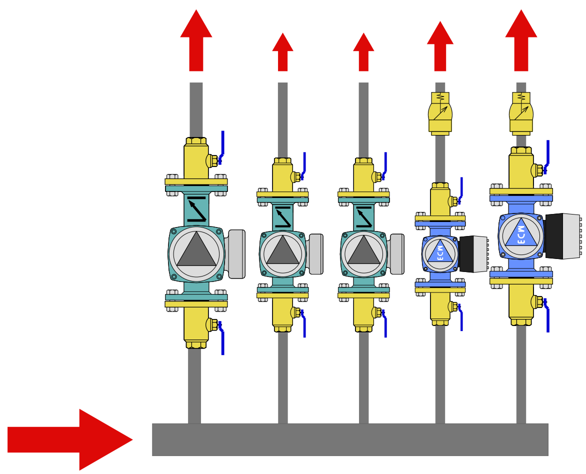
All electric

Hydraulic Separation

What it is.
Why it's important.
How to achieve it.

Hydraulic Separation:

Think of two circulators, operating simultaneously in the same piping assembly, as rival bullies on the same playground.



When 2 or more circulators are operating simultaneously in the same piping assembly, they try to “interfere” with each other.

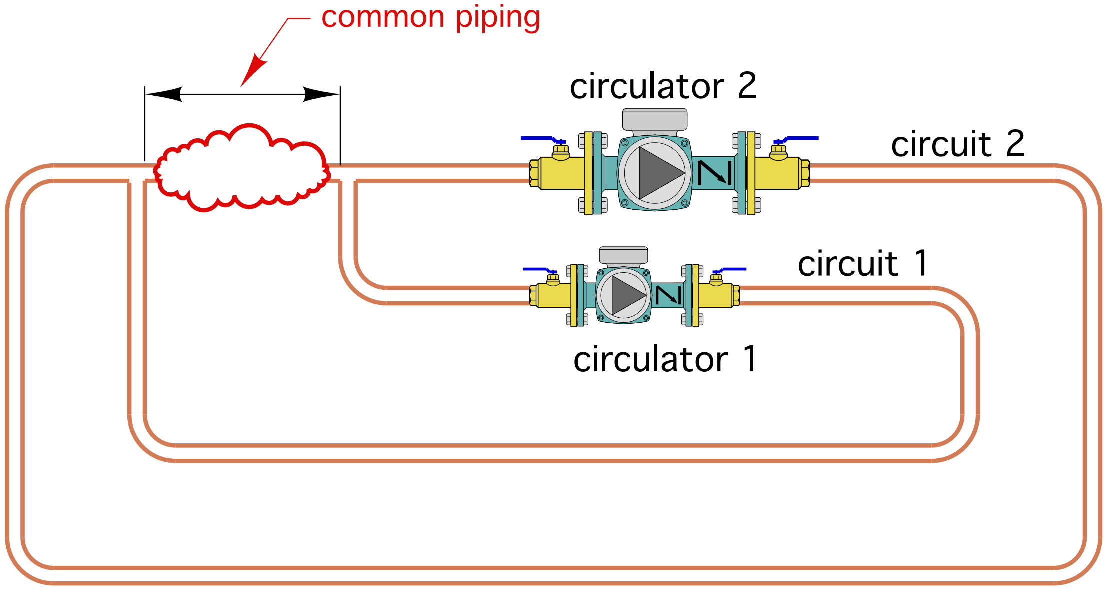
This interference is undesirable!

To avoid this interference the circulators need to be “hydraulically separated” from each other.

There are several ways to do this...

What is "COMMON PIPING?"

It's the piping components shared by two or more circuits.



The degree to which two or more operating circulators interact with each other depends on the head loss of the common piping.

The lower the head loss of the common piping the less the circulators will interfere with each other.

When the head loss of the common piping is very low, there is "hydraulic separation" between the circuits.

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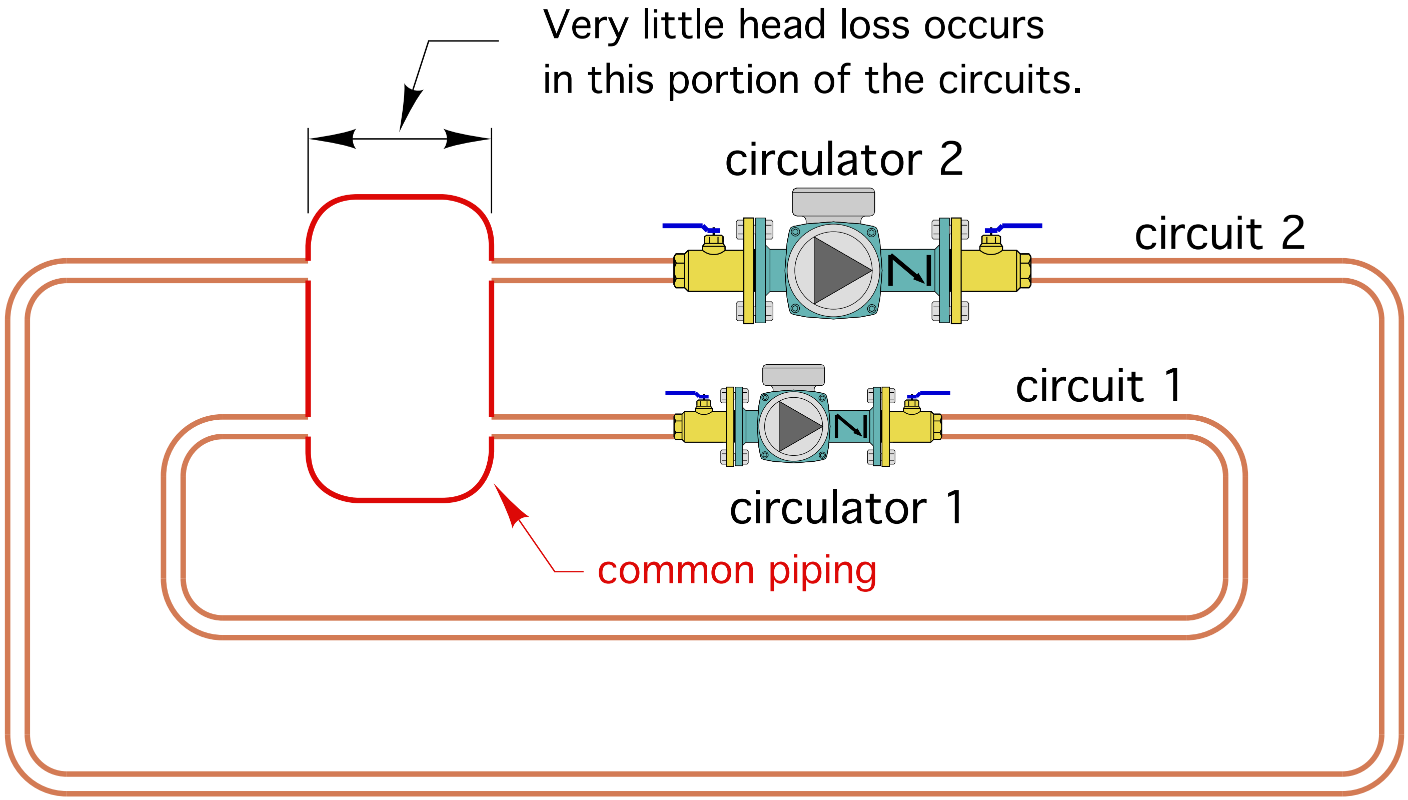
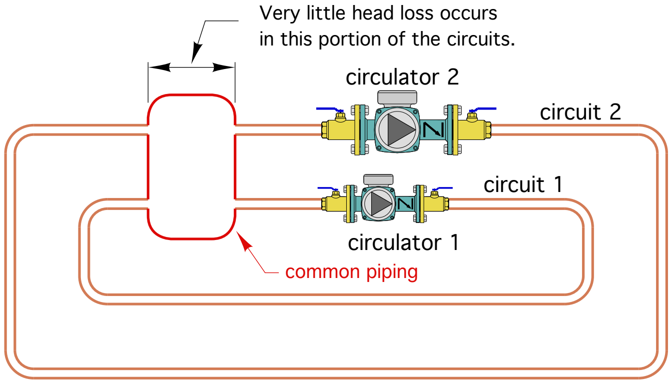




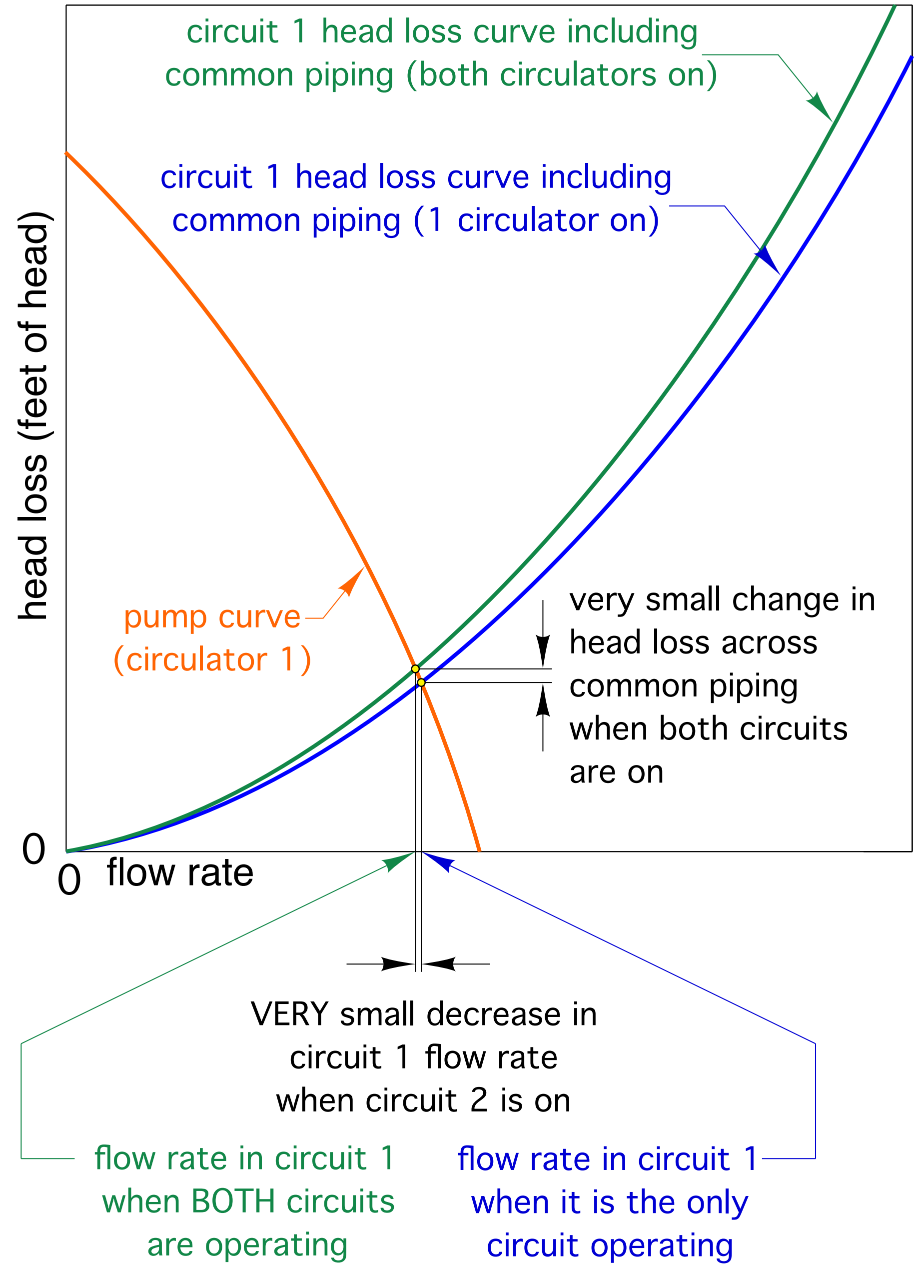
Assume that circulator 1 is operating, but that circulator 2 is off. The lower (blue) system head loss curve in figure 2 applies to this situation.

Next, assume circulator 2 is turned on, and circulator 1 continues to operate.

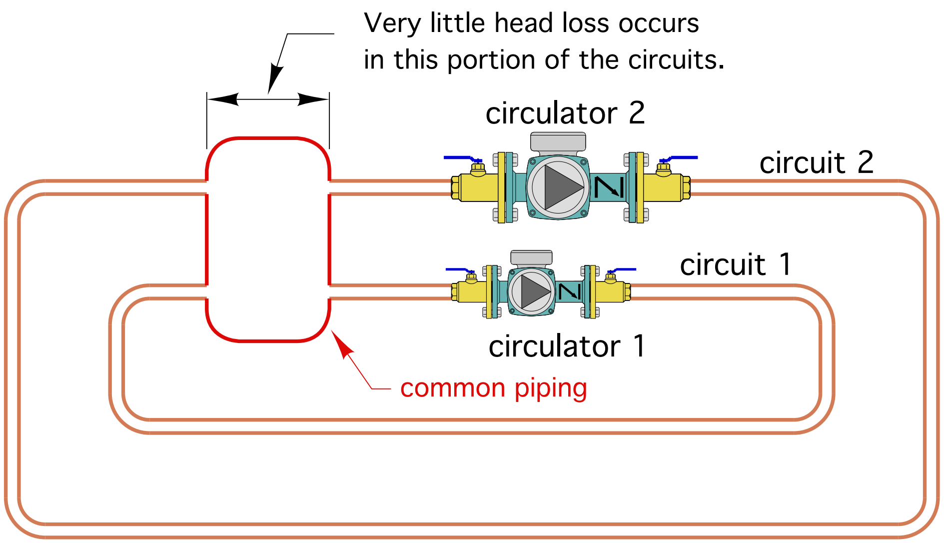
The flow rate through the common piping increases, and so does the head loss across it.

However, because of its spacious geometry, the increase in head loss across the common piping will be very slight. The system head loss curve that is now “seen” by circulator 1 has very slightly steepened. It is the upper, (green) curve shown in figure 2.

The operating point of circuit 1 has moved very slightly to the left, and as a result, the flow rate through circuit 1 has decreased very slightly.



Almost Perfect Is Good Enough:



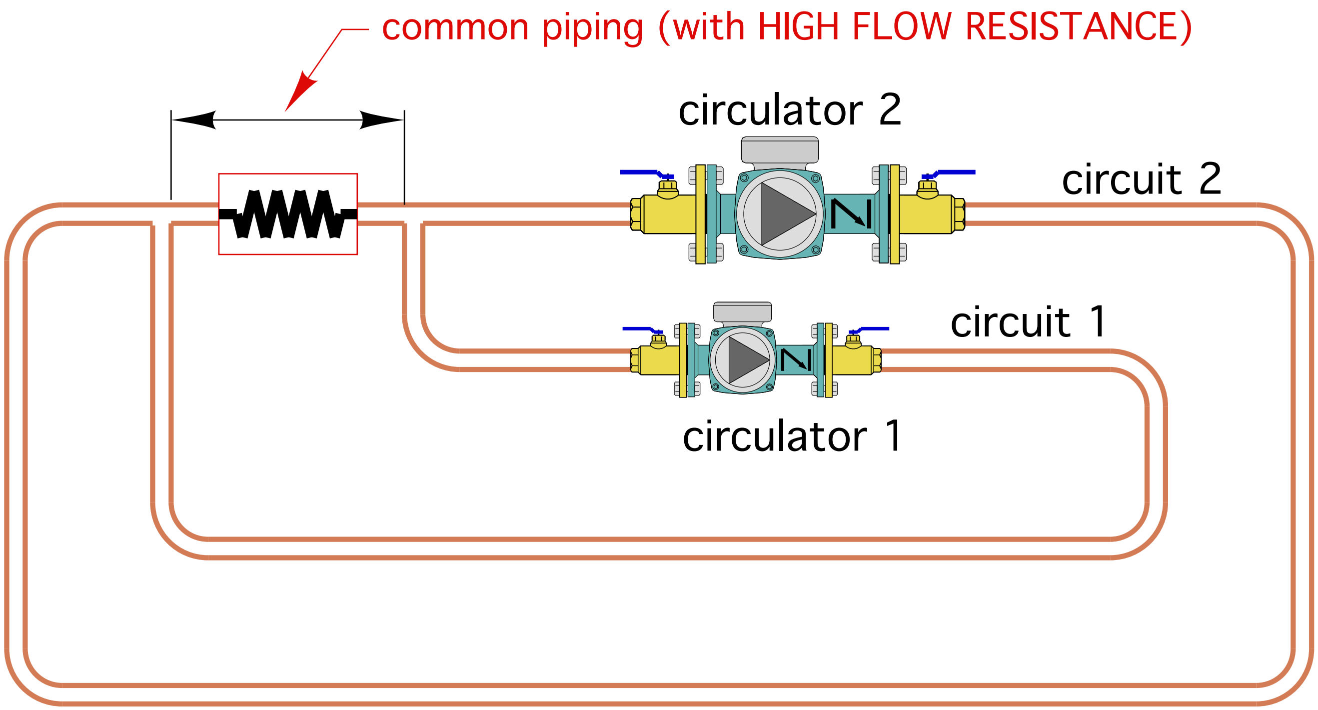
Imagine a hypothetical situation in which the head loss across the common piping was *zero*, even with both circuits operating.

Because **NO** head loss occurs across the common piping, it would be impossible for either circulator to “influence” the other circulator.

This would be “perfect” hydraulic separation.

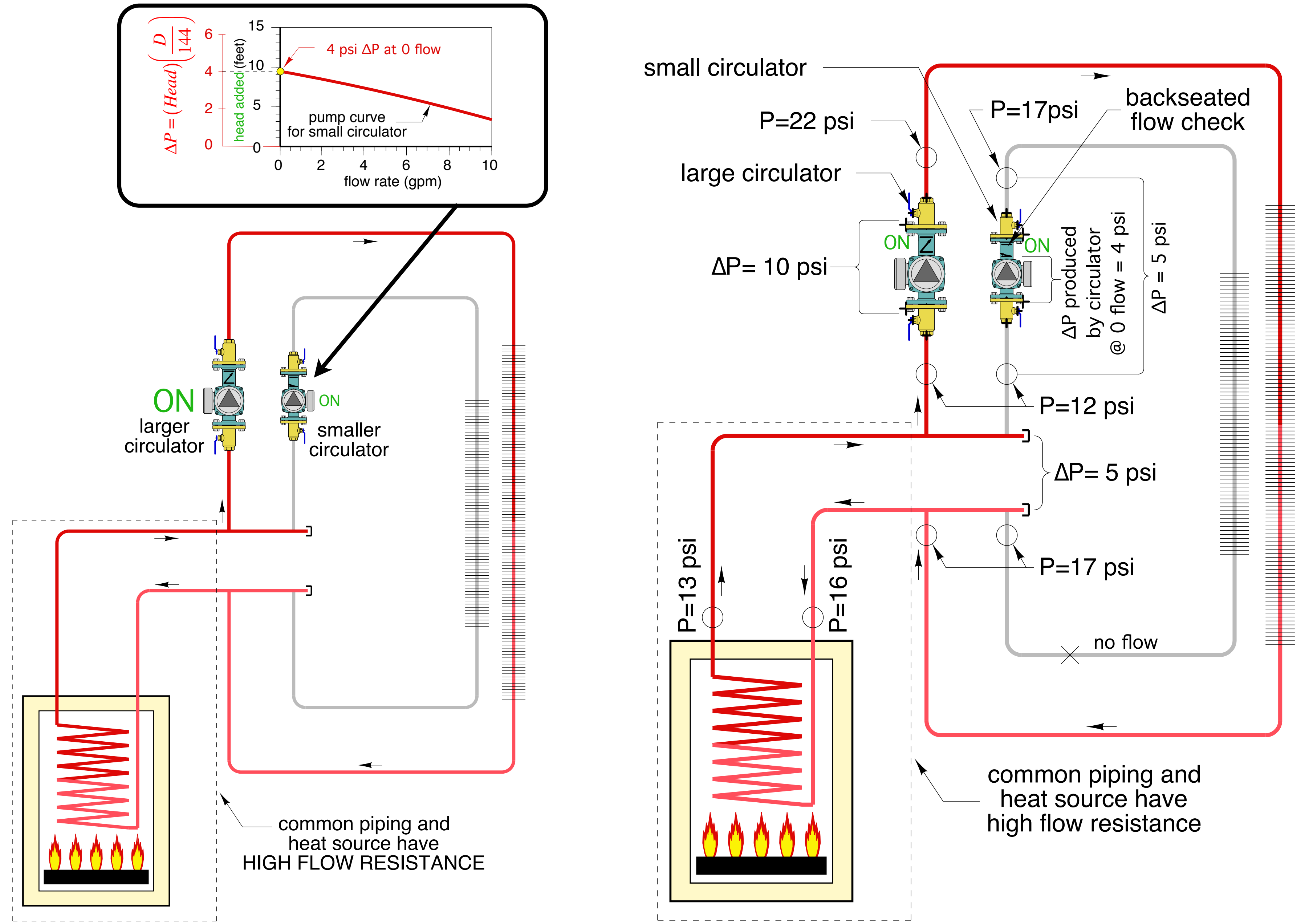
Fortunately, <u>perfect hydraulic separation is not required</u> to ensure that the flow rates through independently operated circuits remain reasonably stable.

Common piping with high flow resistance is NOT good:



The higher the flow resistance of the common piping, the more each circulator will “influence” flow in the other circuit (e.g. the lower the hydraulic separation of the circuits.

High flow resistance common piping - something to avoid

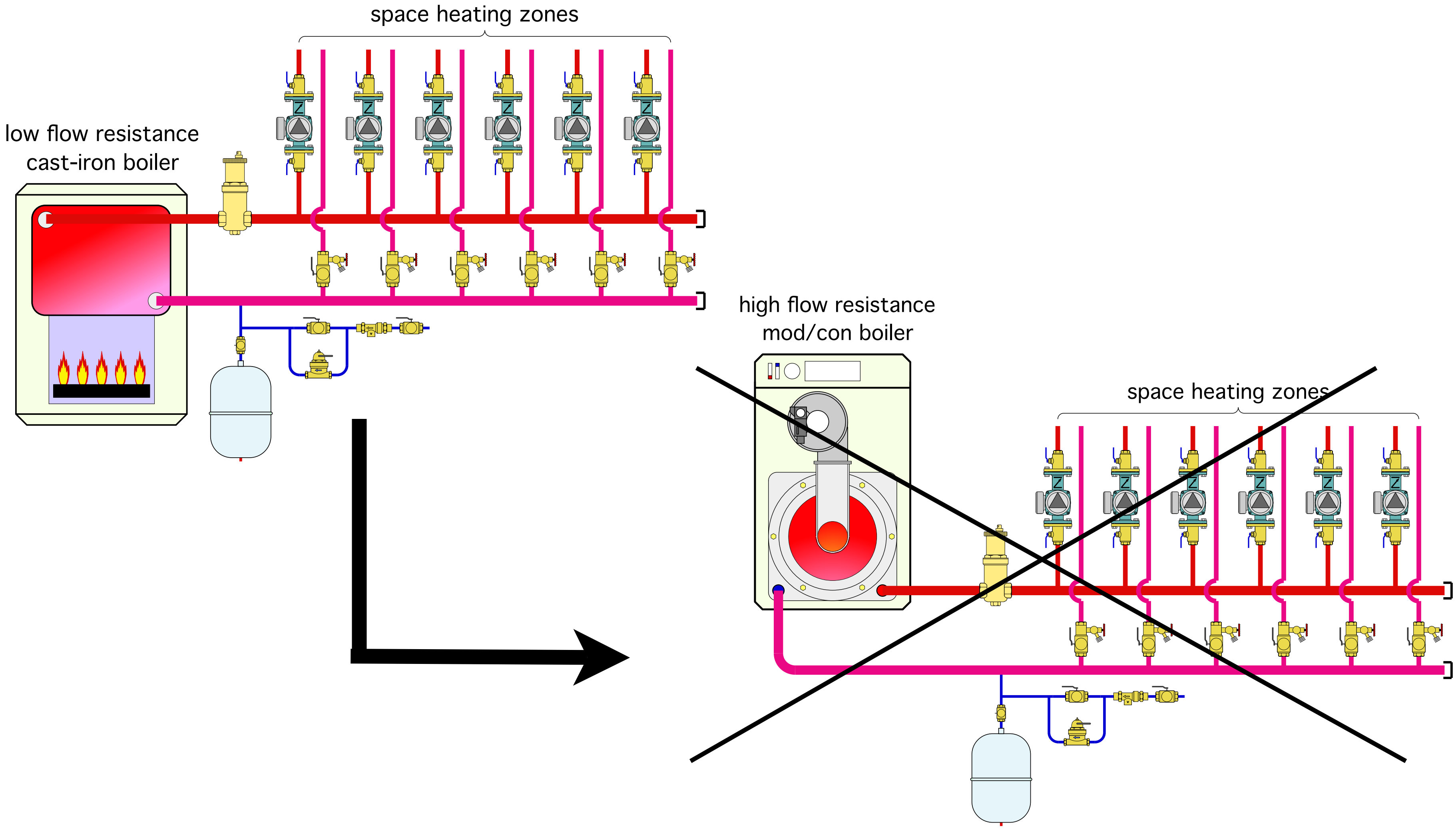


Conventional cast-iron boilers have very **low** flow resistance.

Modern compact boilers have ***much higher*** flow resistance.

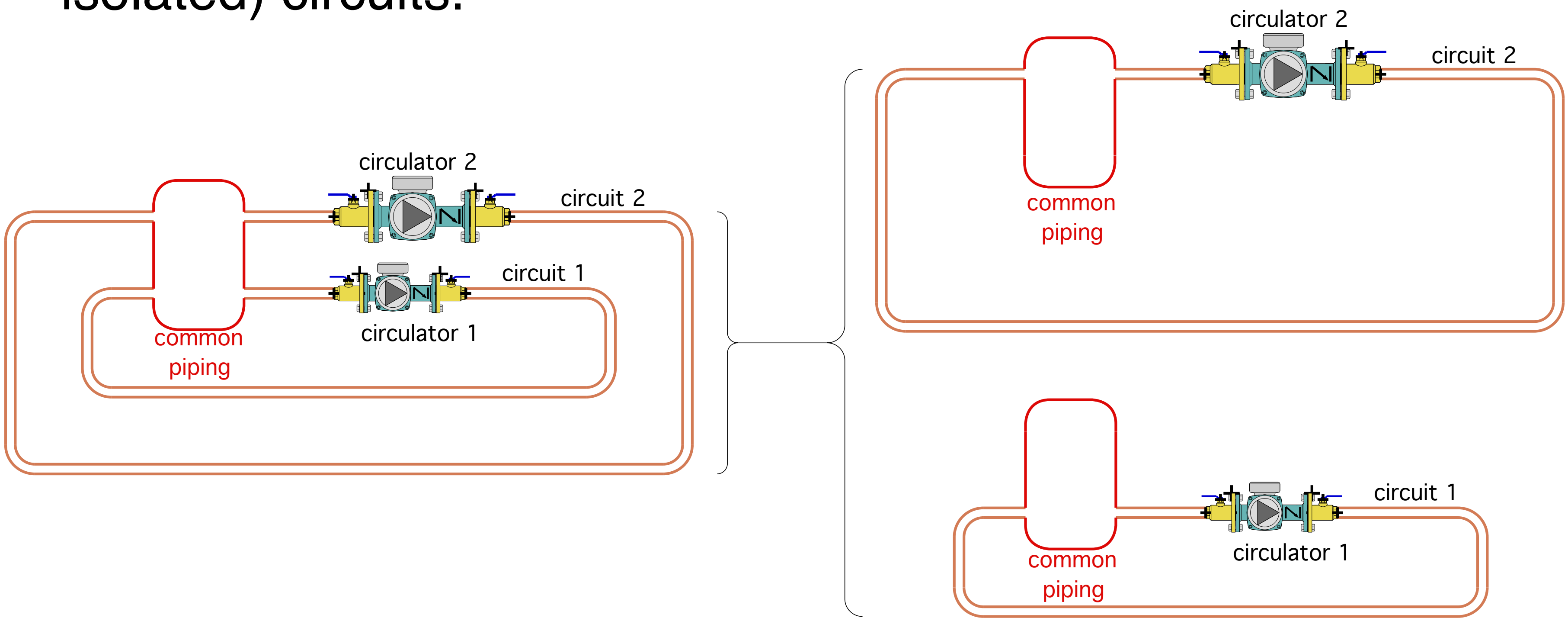
If a compact boiler is “cut and soldered” in place to replace a cast iron boiler,

Interference between simultaneously operating circulators is likely.



Divide & Conquer:

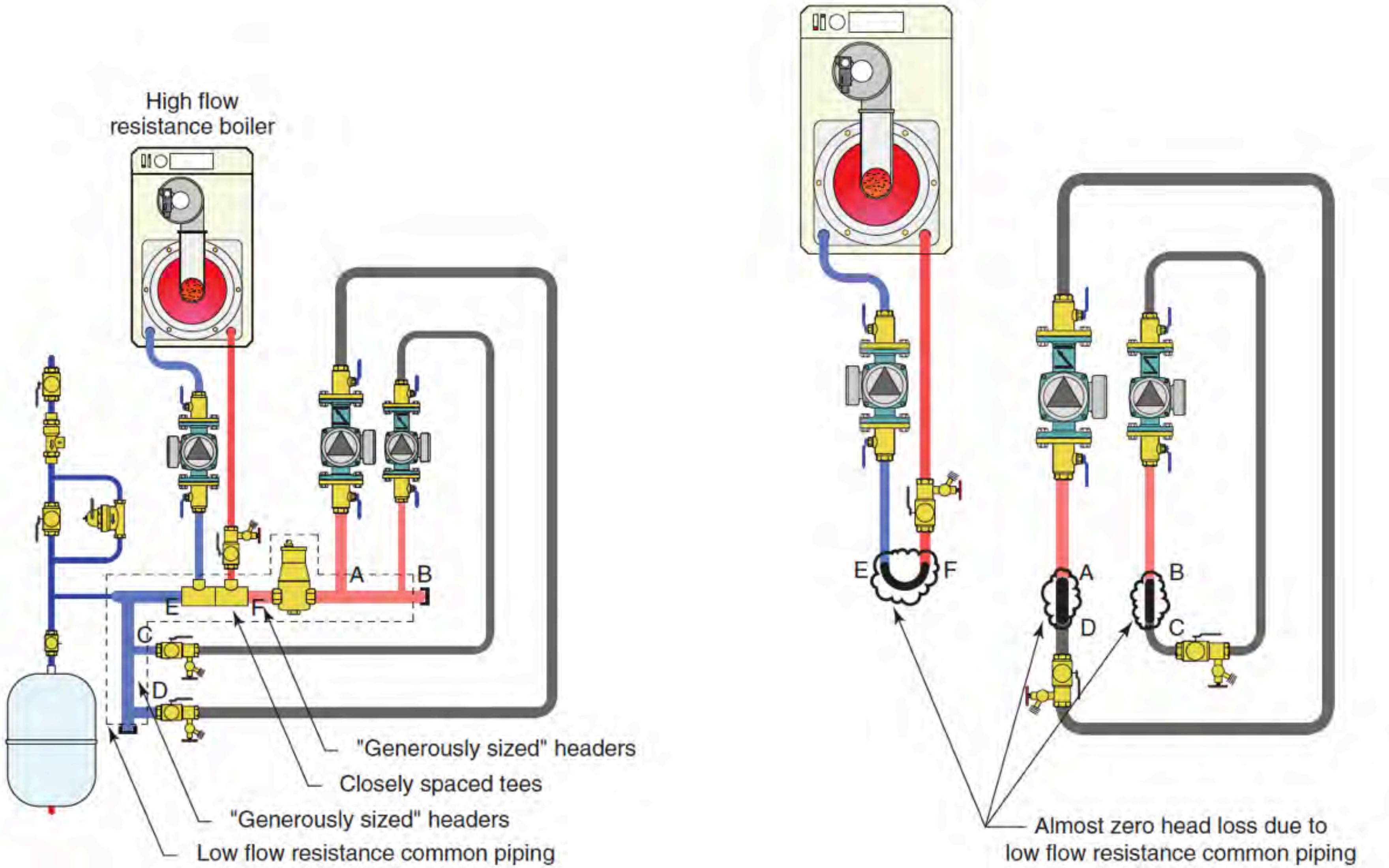
Hydraulic separation allows designers to think of an overall system as a collection of independent ("hydraulically isolated) circuits.



From the standpoint of hydraulics, each circuit can be designed as if it's a stand-along circuit.

Divide & Conquer:

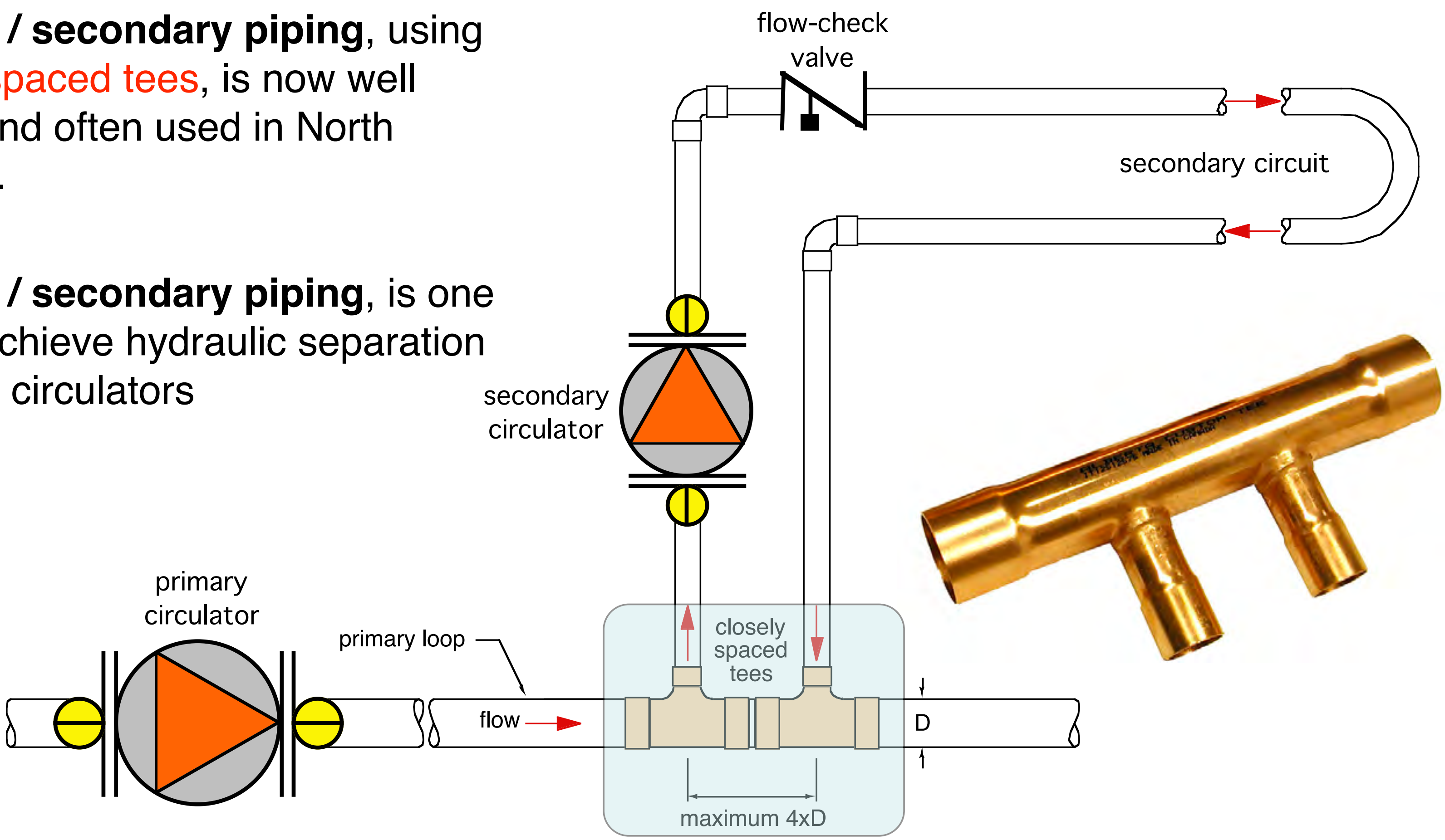
- Simplifying system analysis
- Preventing flow interference



Primary / Secondary piping - *where it all began...*

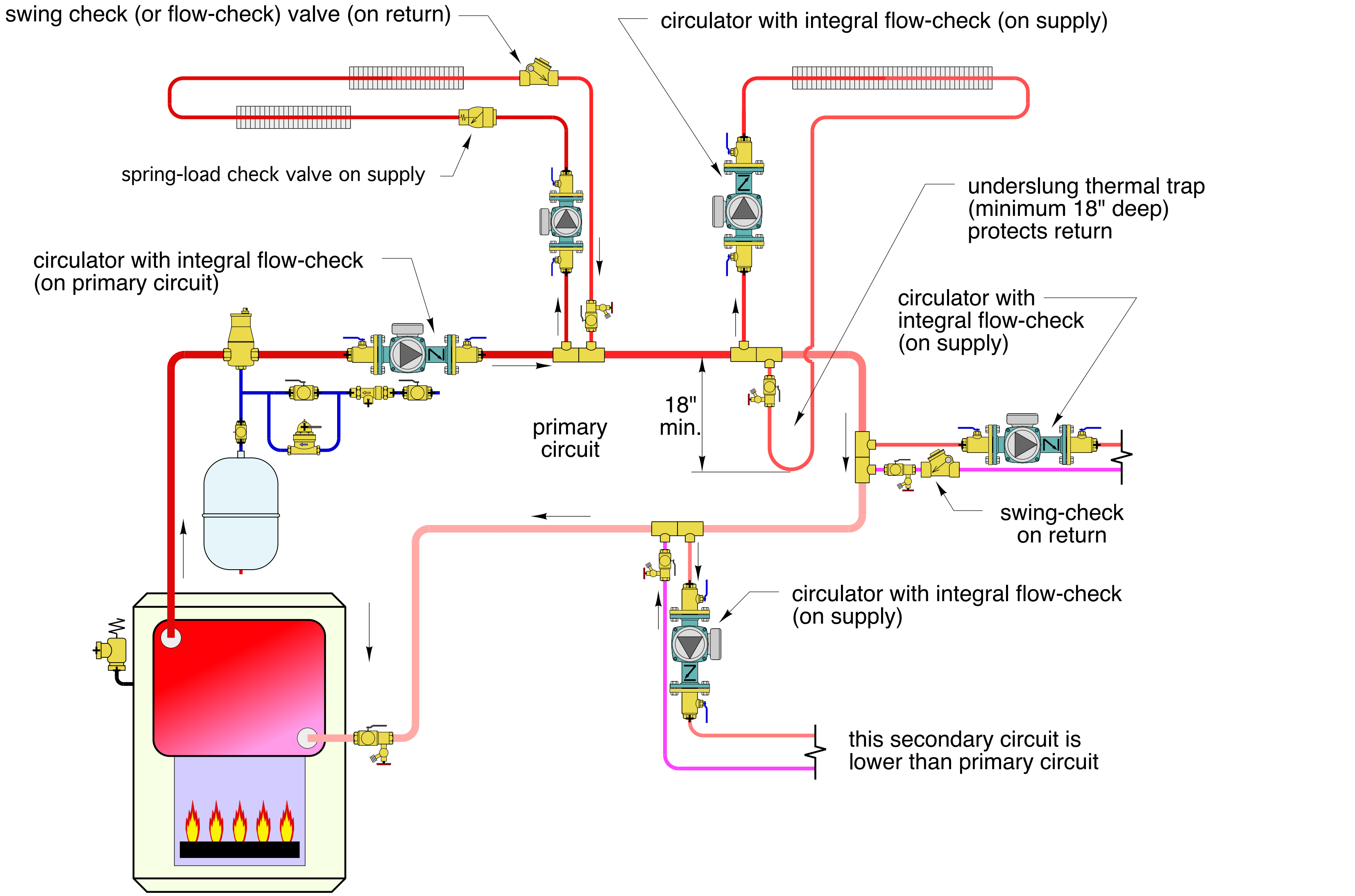
Primary / secondary piping, using closely spaced tees, is now well known and often used in North America.

Primary / secondary piping, is one way to achieve hydraulic separation between circulators



But primary / secondary piping is not the ONLY way to create hydraulic separation...

Primary / secondary piping (one way to provide hydraulic separation)



This is a SERIES primary loop. It will create a sequential drop in water temperature from one secondary circuit to the next.

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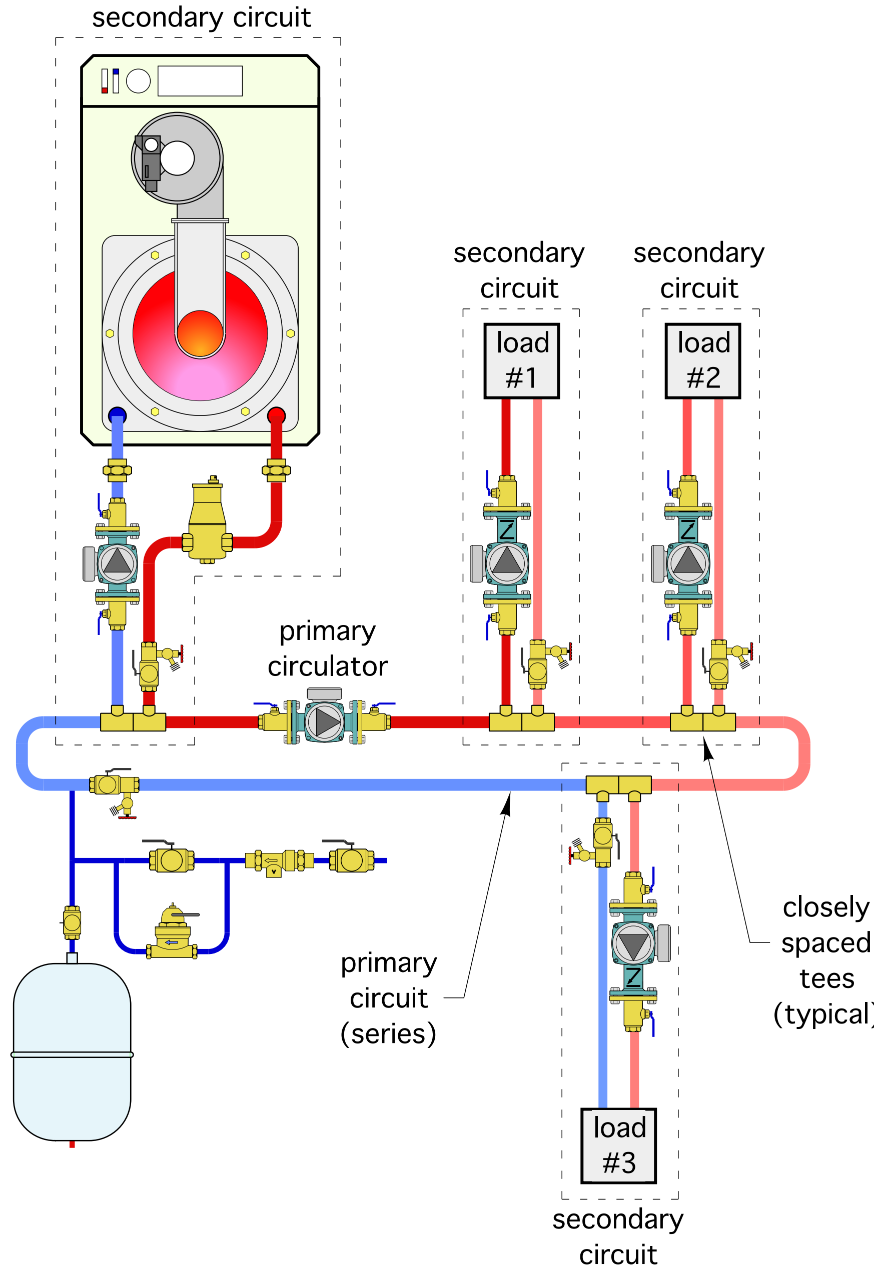
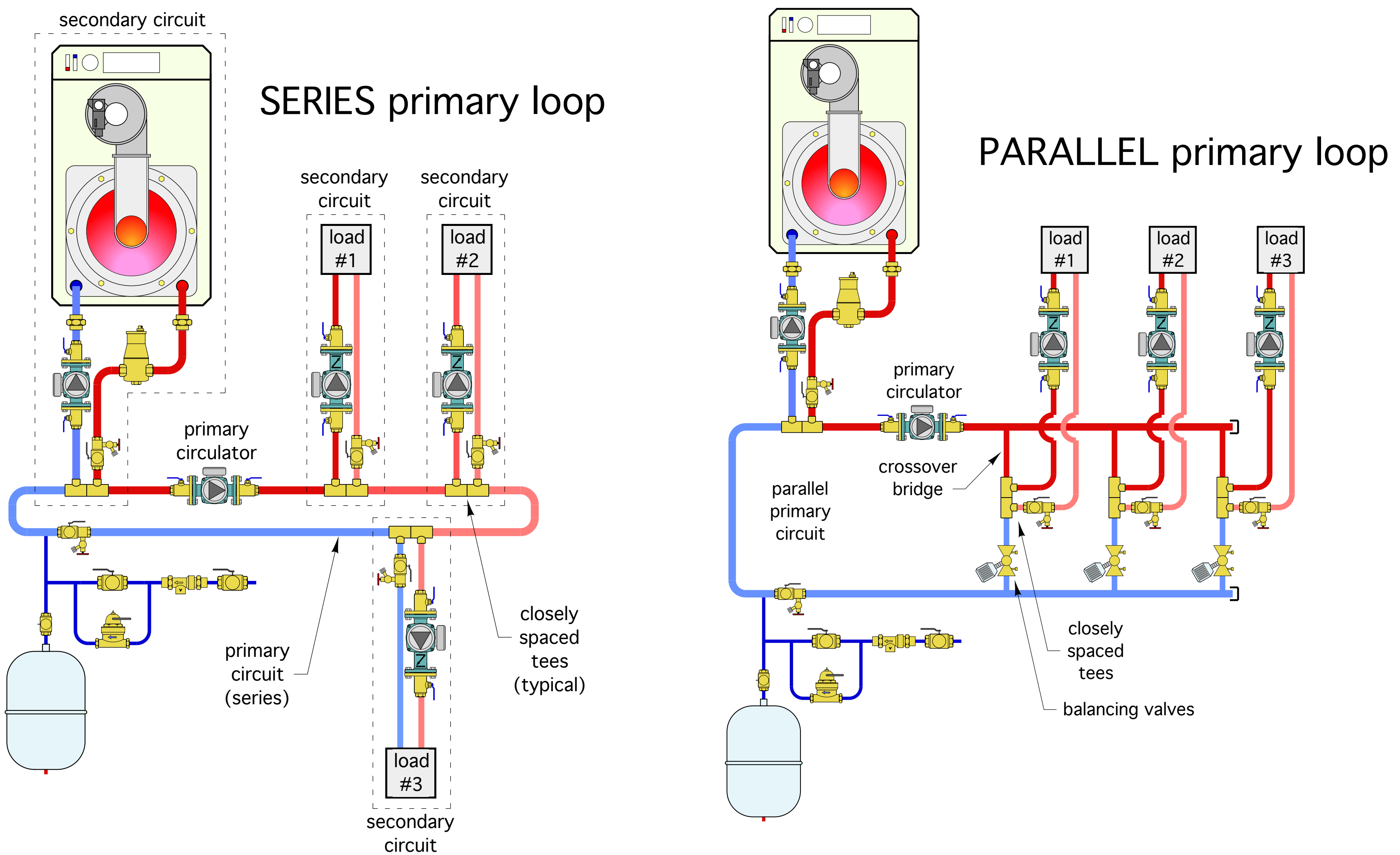


Series and parallel primary/secondary systems



Both series and parallel primary/secondary systems **require a primary circulator.**

This adds to the installed cost of the system AND **adds hundreds, even thousands of dollars in operating cost** over a typical system life.

An example of primary loop circulator operating cost:

Consider a system that supplies 500,000 Btu/hr at design load. Flow in the primary loop is 50 gpm with a corresponding head loss of 15 feet (6.35 psi pressure drop). Assume a wet rotor circulator with wire-to-water efficiency of 25 is used as the primary circulator.

The input wattage to the circulator can be estimated as follows:

$$W = \frac{0.4344 \times f \times \Delta P}{0.25} = \frac{0.4344 \times 50 \times 6.35}{0.25} = 552 watts$$

Assuming this primary circulator runs for 3000 hours per year its first year operating cost would be:

$$\text{1st year cost} = \left(\frac{3000hr}{yr}\right)\left(\frac{552w}{1}\right)\left(\frac{1kwhr}{1000whr}\right)\left(\frac{\$0.10}{kwhr}\right) = \$165.60$$

An example of primary loop circulator operating cost:

Assuming electrical cost escalates at 4% per year the total operating cost over a 20-year design life is:

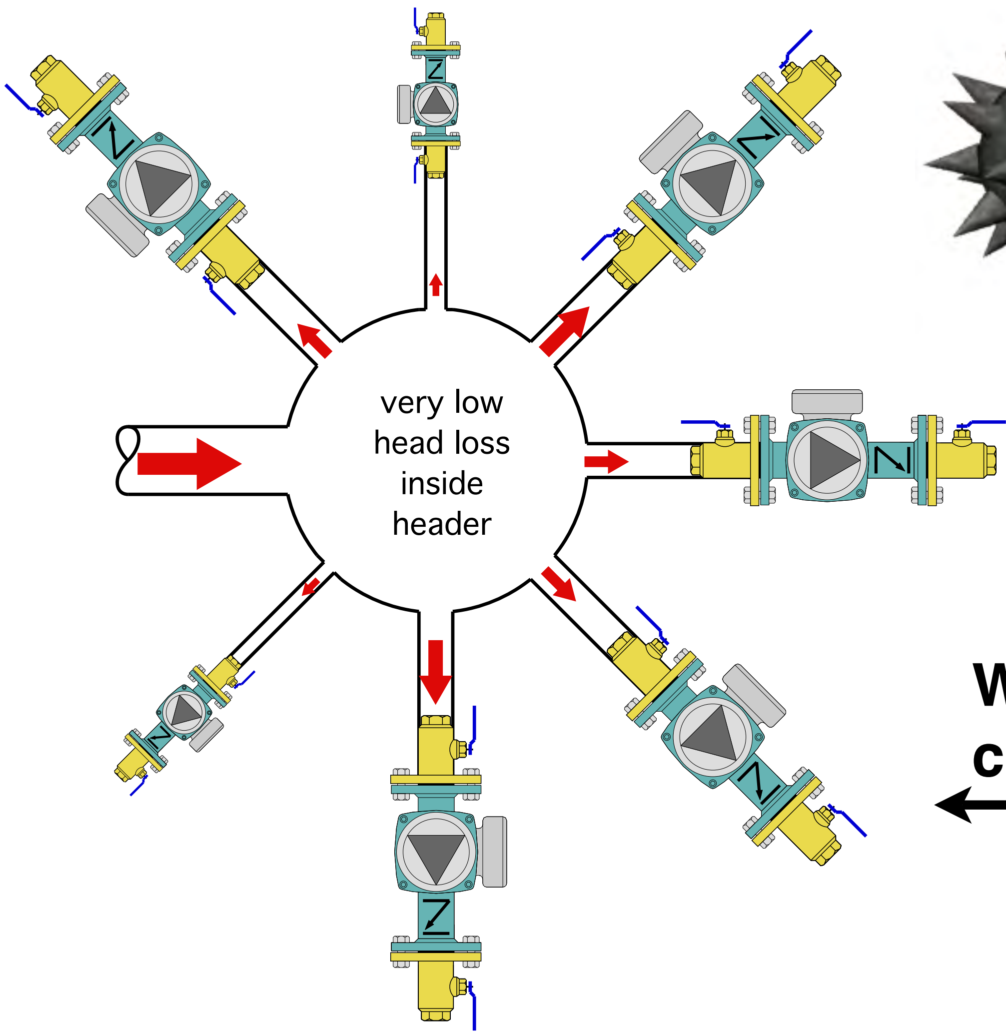
$$c_T = c_1 \times \left(\frac{(1+i)^N - 1}{i} \right) = \$165.60 \times \left(\frac{(1+0.04)^{20} - 1}{0.04} \right) = \$4,931$$

This, combined with eliminating the multi-hundred dollar installation cost of the primary circulator obviously results in significant savings.

Question: What is the "ideal" header in a hydronic system?

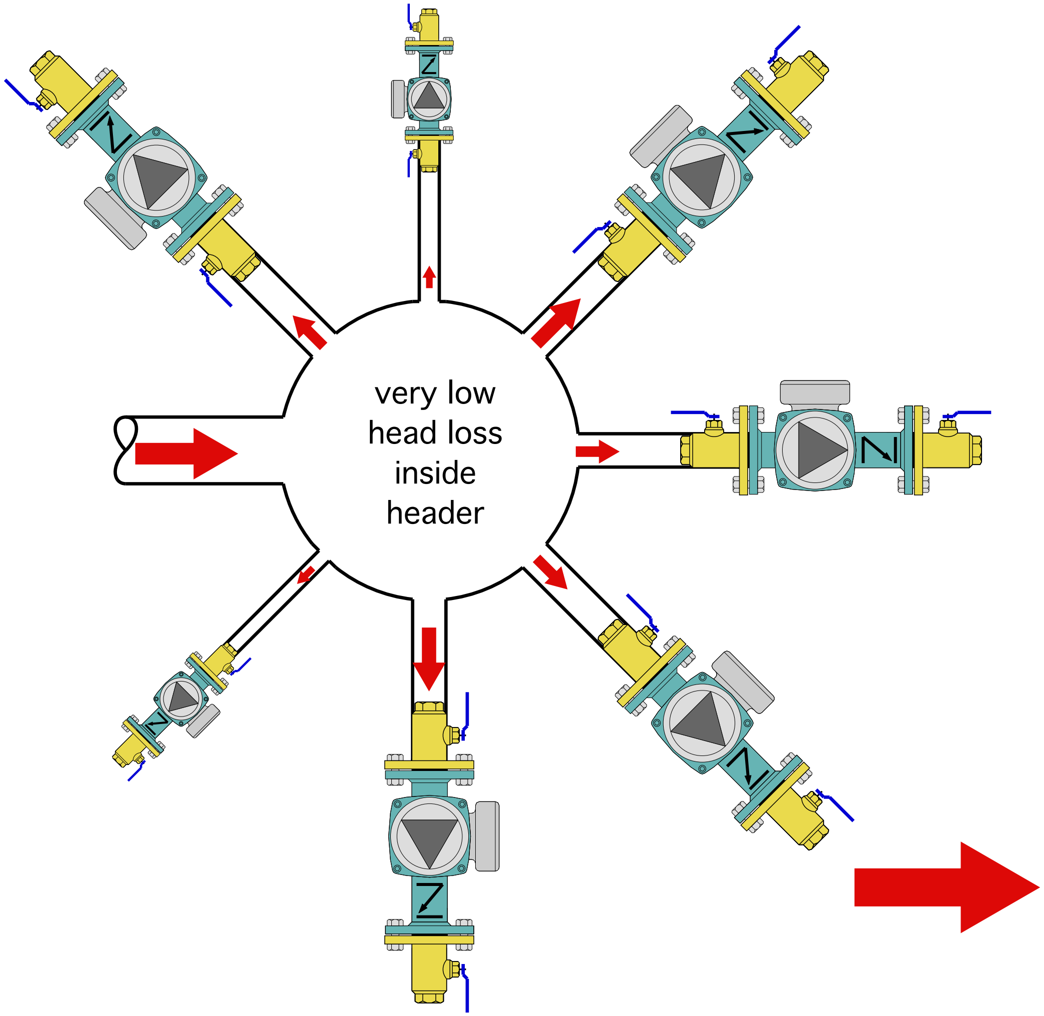
Answer: One that splits up the flow without creating head loss

Think about a "**copper basketball**" with pipes sticking out of it in all directions.

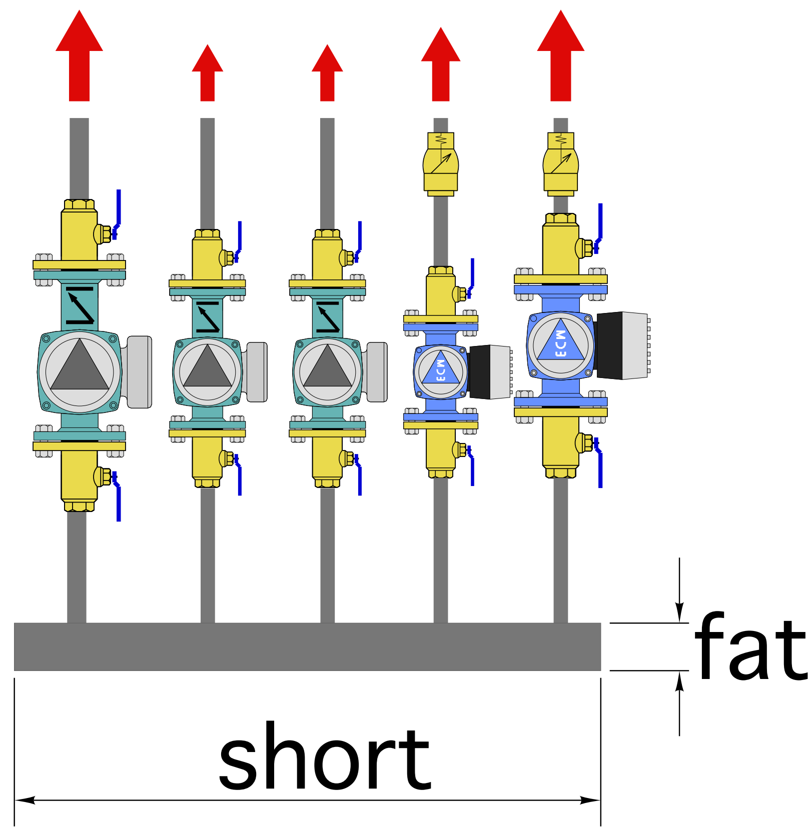


Wouldn't this be pretty close to an ideal header???

So why don't we build headers like this???



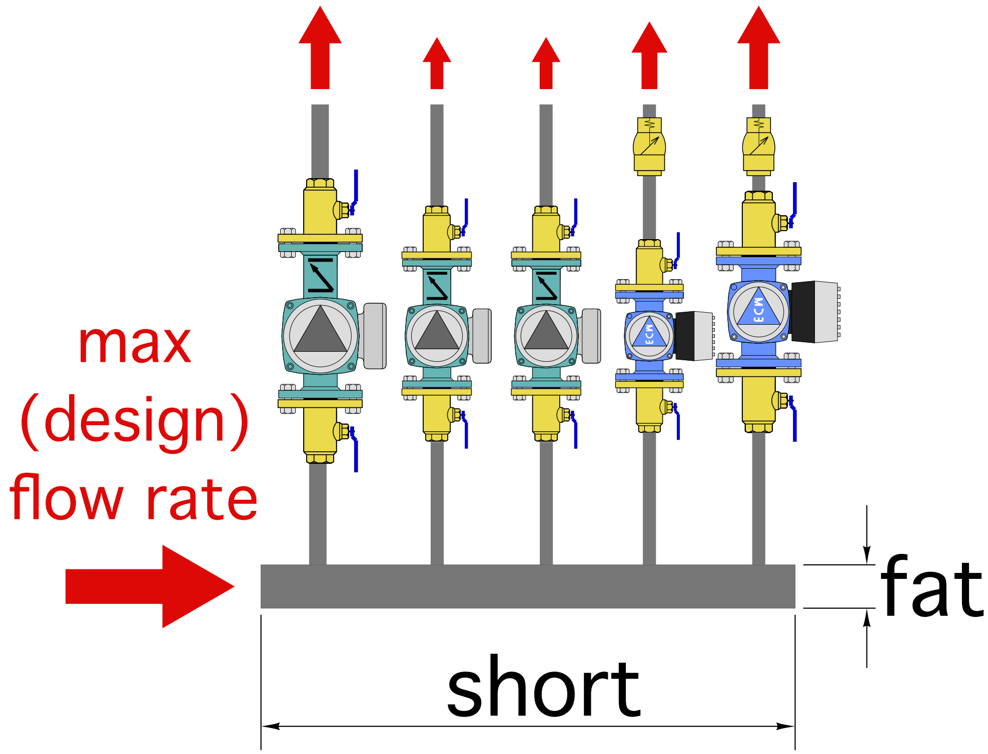
Instead, we approximate the ideal header by making it "short" & "fat"



Short / fat headers are GOOD!

Long / skinny headers are BAD!

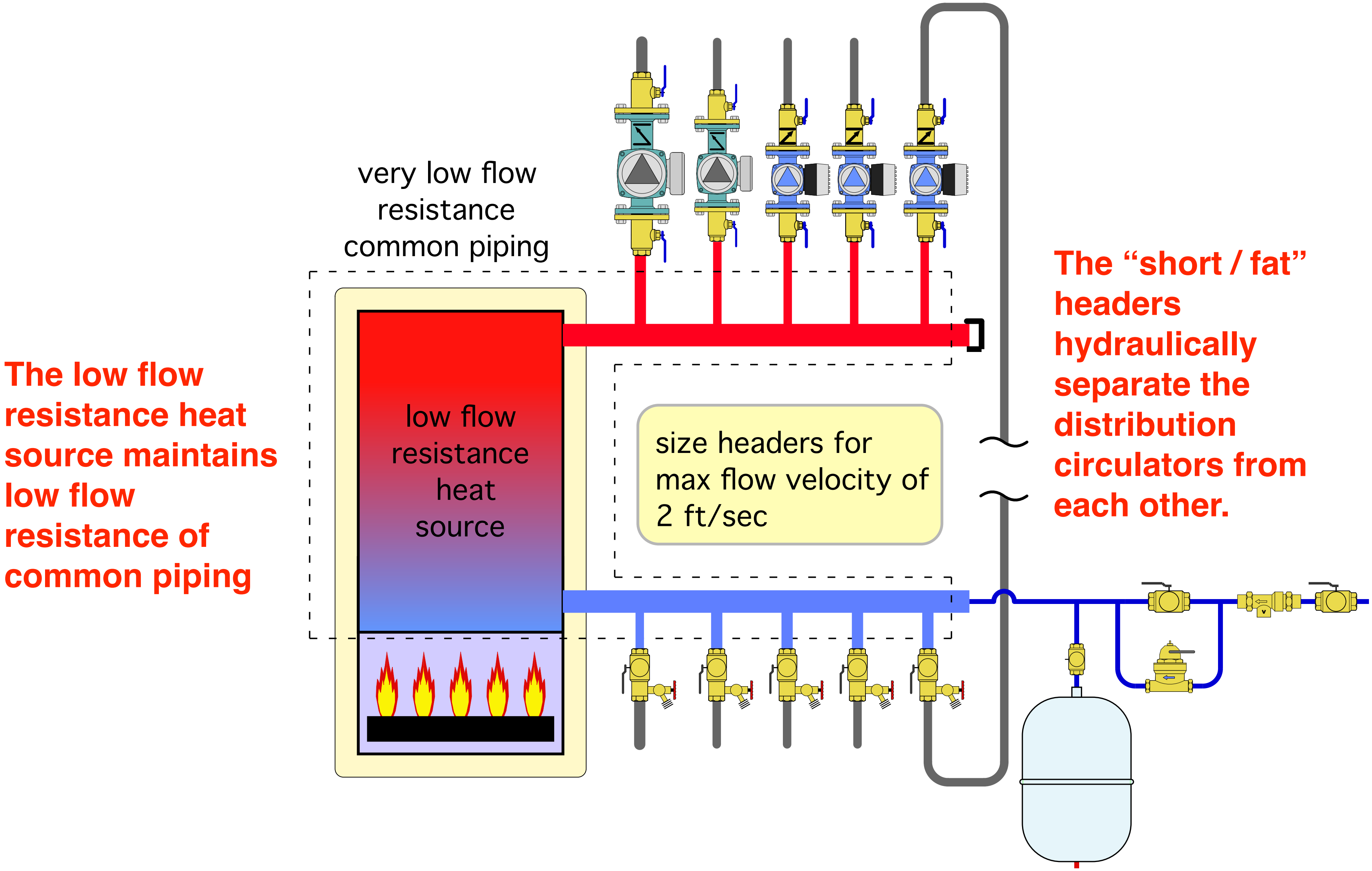
So what's EXACTLY is a short / fat header???



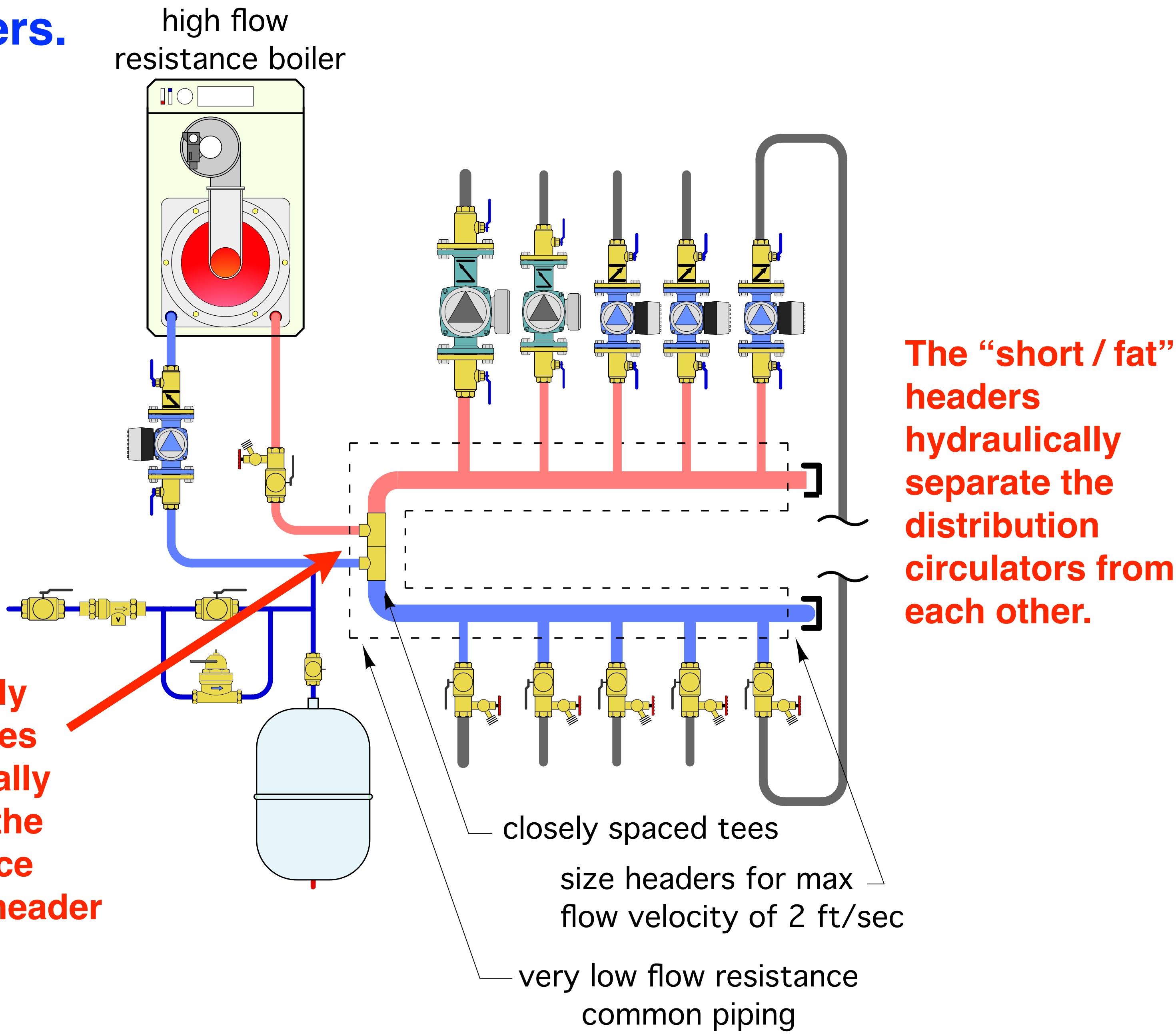
select pipe size that yields a flow velocity no higher than 2 feet per second

Tubing	Flow rate to establish 2 ft/sec flow velocity
1/2" type M copper	1.6 gpm
3/4" type M copper	3.2 gpm
1" type M copper	5.5 gpm
1.25" type M copper	8.2 gpm
1.5" type M copper	11.4 gpm
2" type M copper	19.8 gpm
2.5" type M copper	30.5 gpm
3" type M copper	43.6 gpm

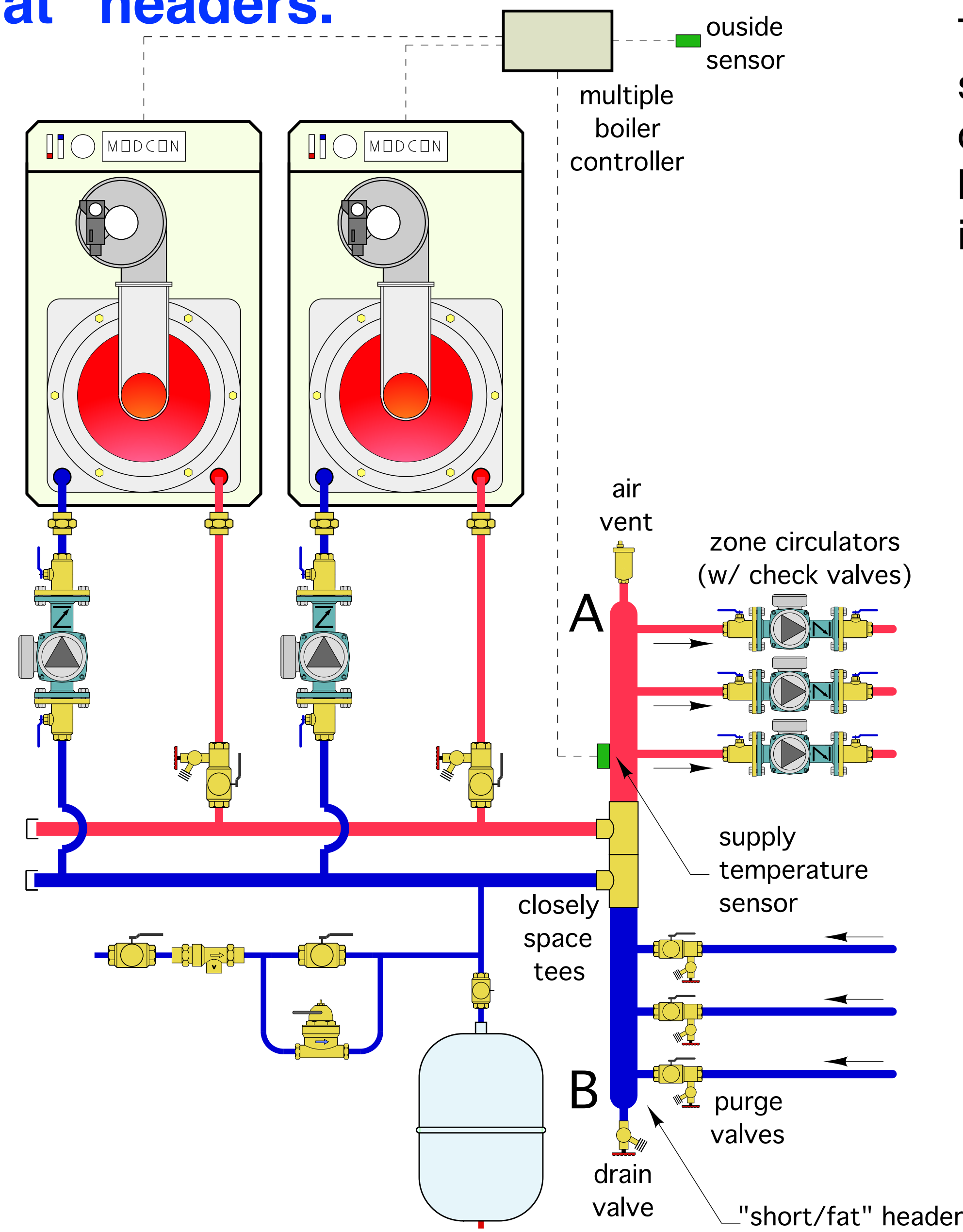
Hydraulic separation achieved by low flow resistance heat source & “short / fat” headers.



Hydraulic separation achieved by closely spaced tees & “short / fat” headers.



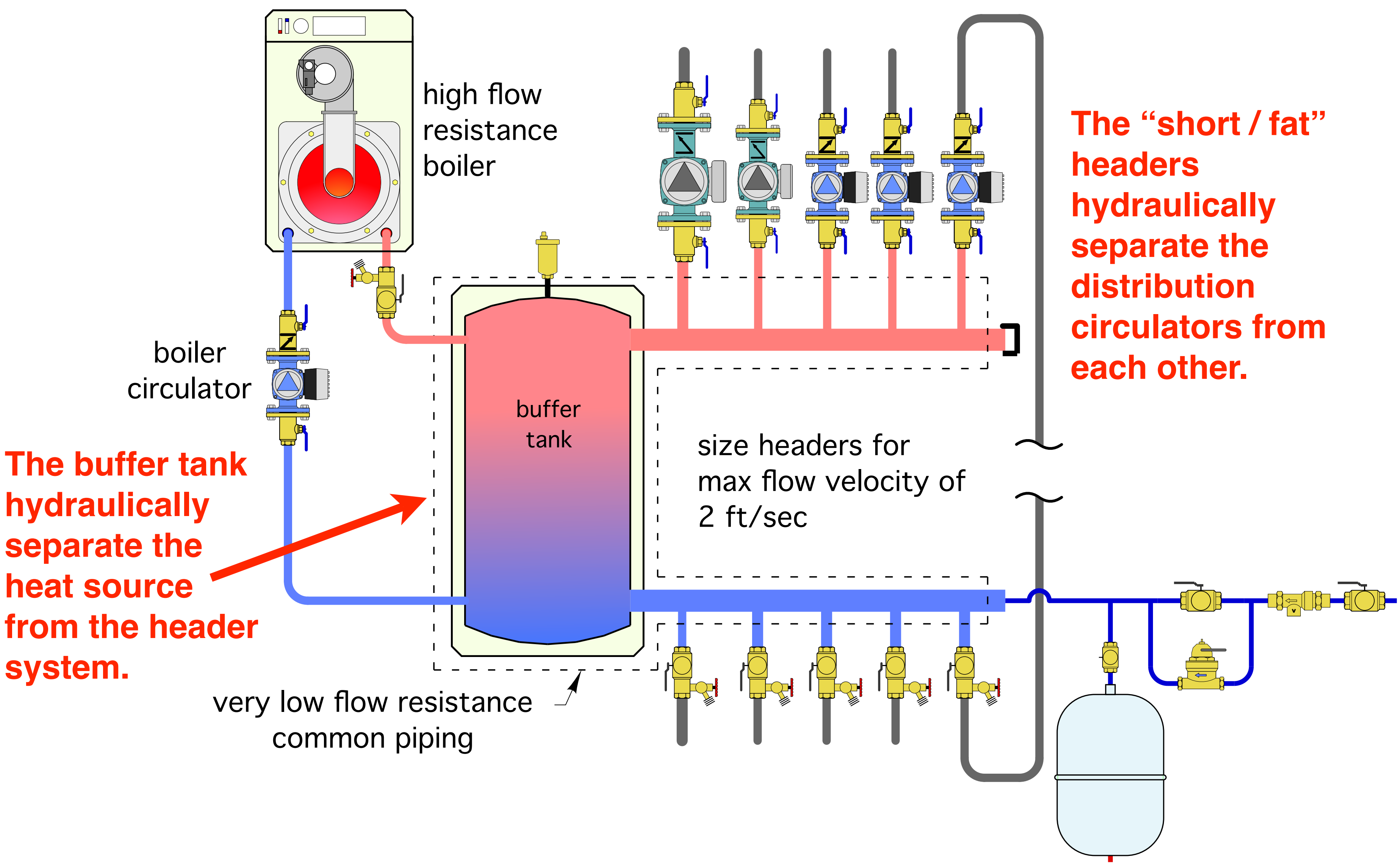
Hydraulic separation achieved by **closely spaced tees & “short / fat” headers.**



The “short & fat” header and close spacing between supply and return connections results in a low pressure drop between points A and B. Each load circuit is hydraulically separated from the others.

- **Header should be sized for max. flow velocity of 2 feet per second**
- **Each circuit must include a check valve.**
- **The supply temperature sensor must be downstream of the point of hydraulic separation.**
- **The header can be vertical (as shown) or horizontal.**

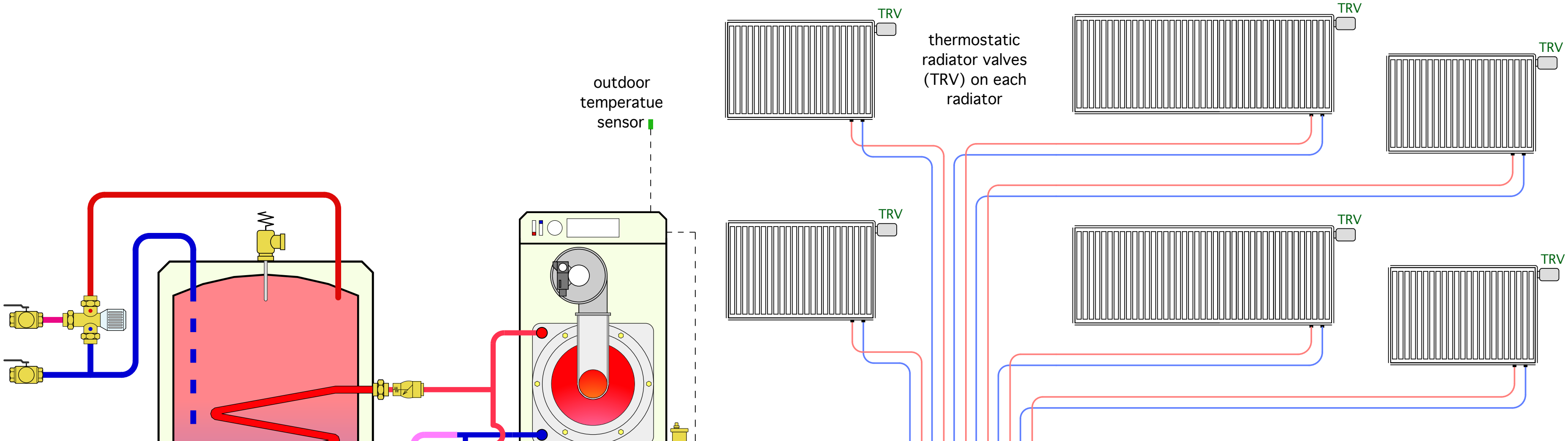
Hydraulic separation achieved by buffer tank (piped as shown) & "short / fat" headers.



Hydraulic Separation in “Micro-load” systems:

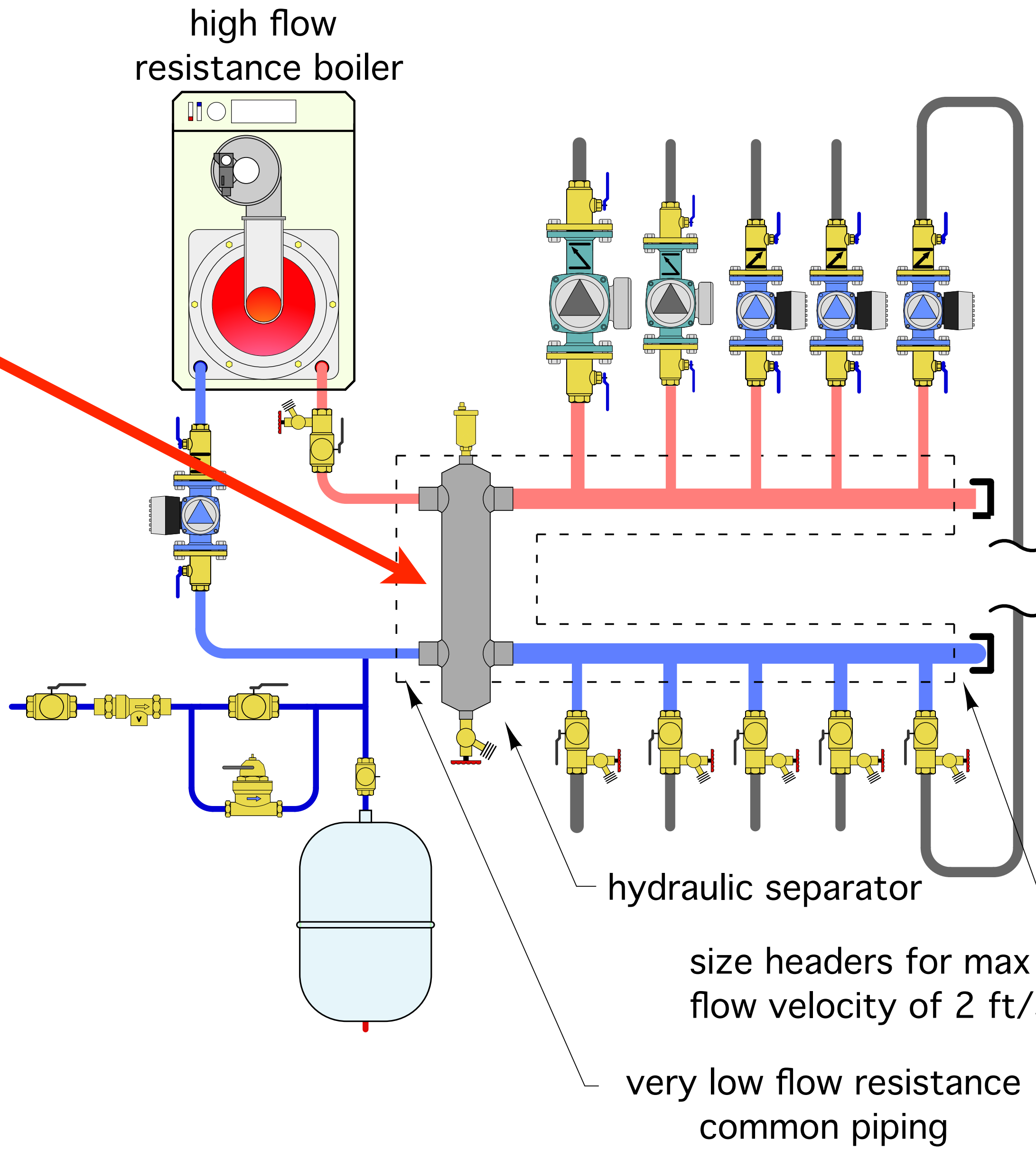
The small insulated tank provides:

- Thermal buffering
- Hydraulic separation
- Air separation and collection
- Sediment separation and collection



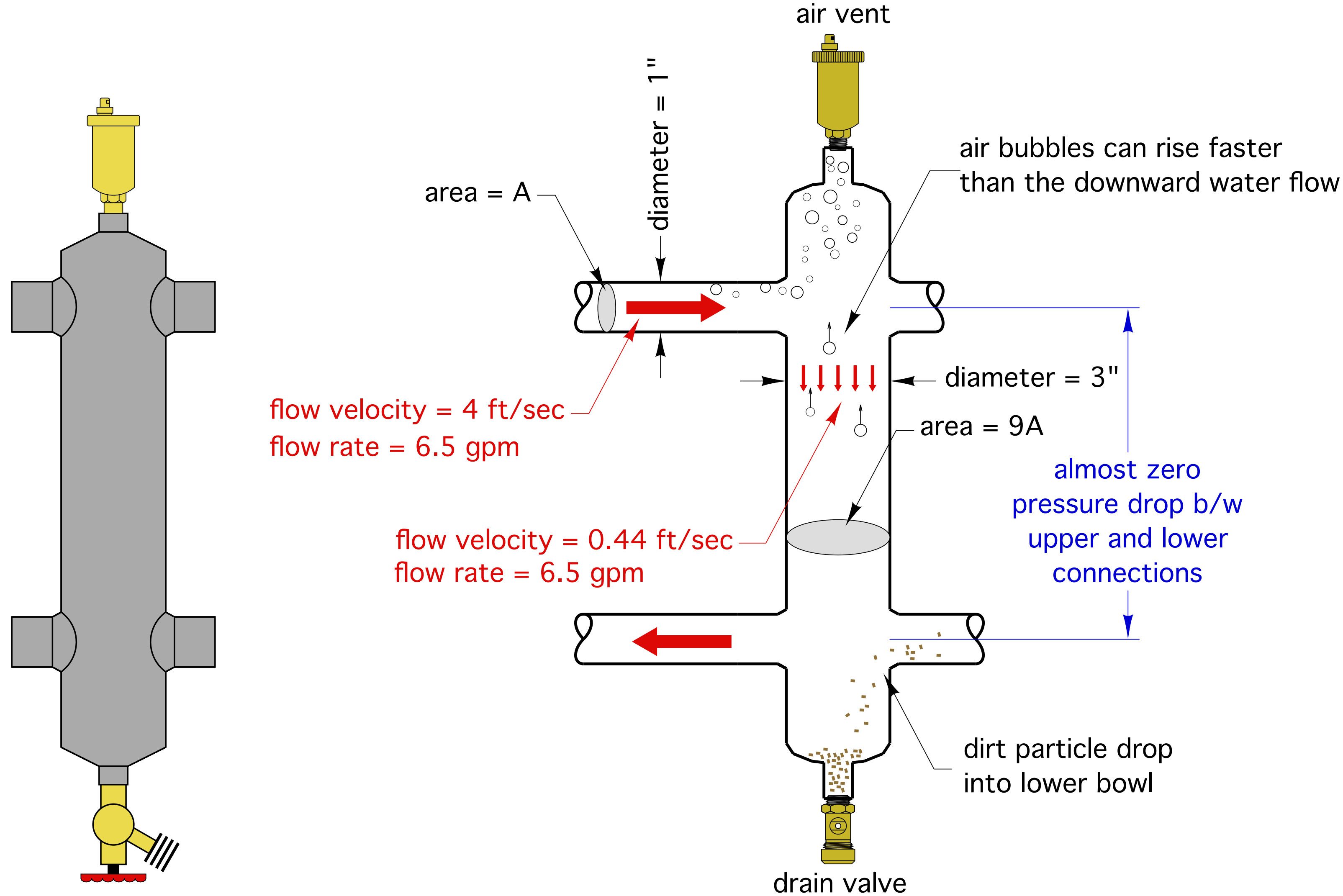
Hydraulic separation achieved by hydraulic separator.

The hydraulic separator hydraulically separates the heat source from the header system.



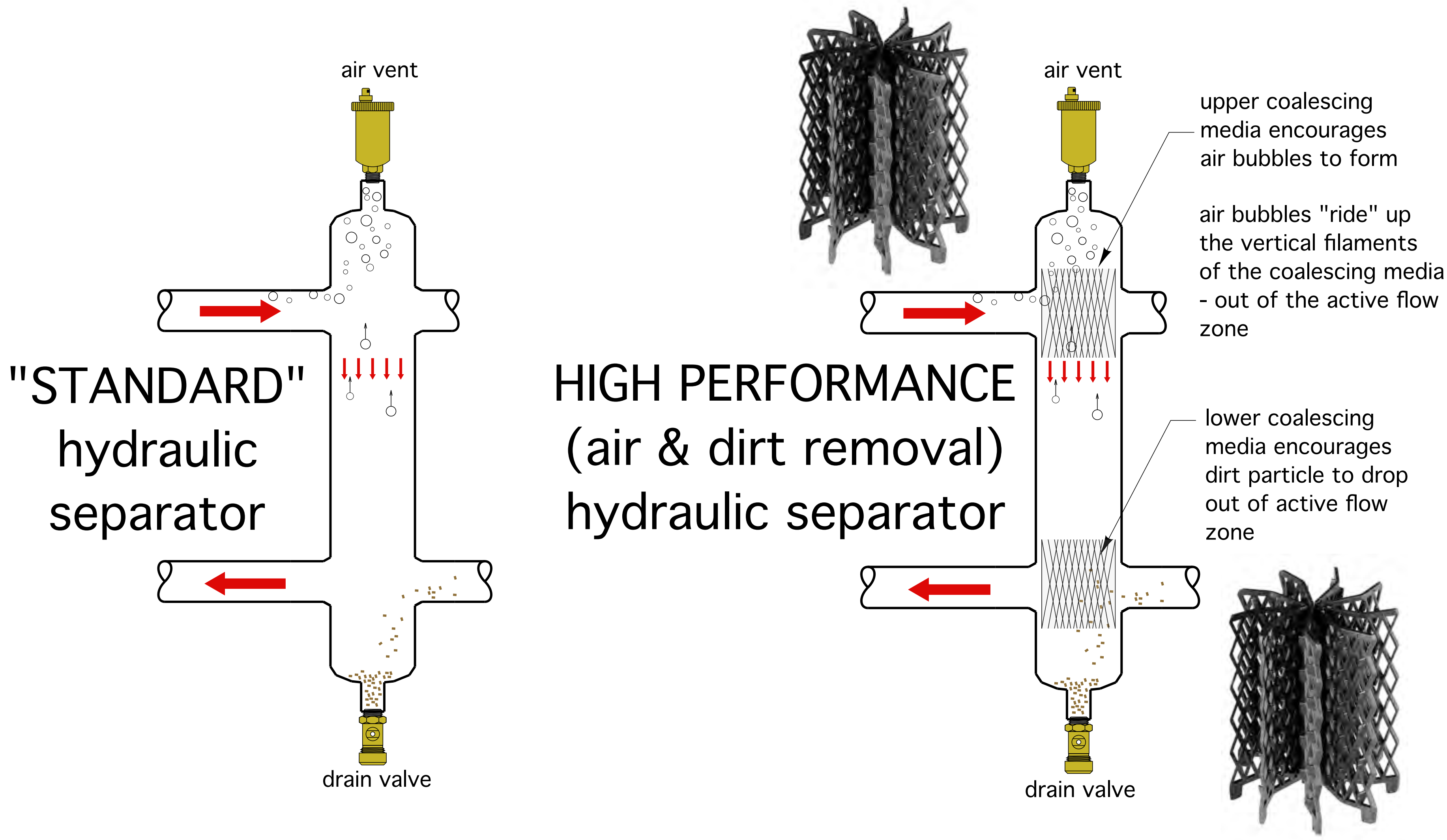
The "short / fat" headers hydraulically separate the distribution circulators from each other.

What’s going on inside a hydraulic separator?



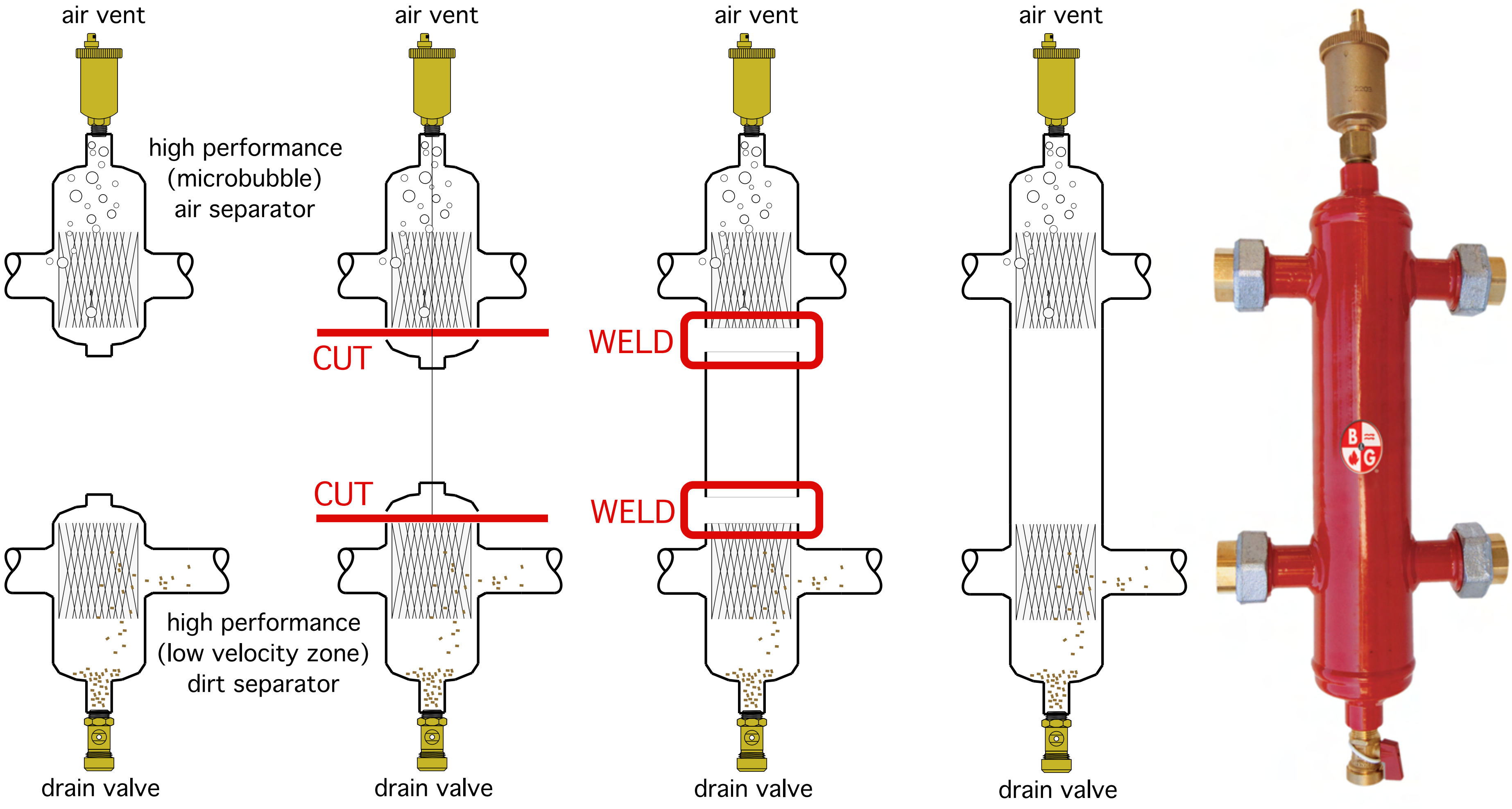
The low vertical velocity inside the separator produces minimal pressure drop top to bottom. Thus there is very little tendency to induce flow on the load side of the separator.

What does the “coalescing media” do inside a hydraulic separator?



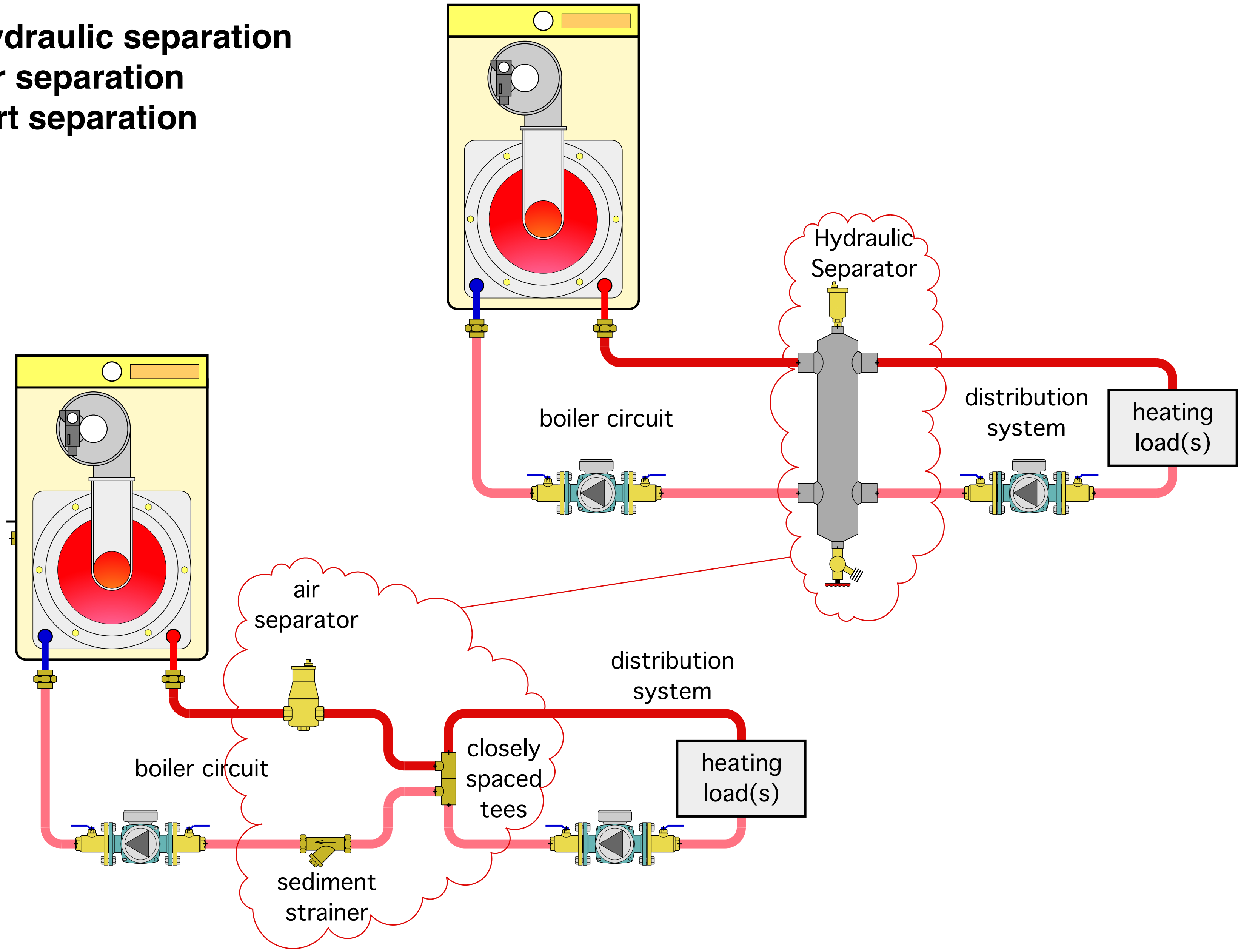
The coalescing media creates tiny vortices that cause gas molecules (mostly oxygen and nitrogen) to form microbubbles. The media also helps microbubble merge together and rise upward out of the active flow zone.

Why companies that offer air and dirt separators also offer hydraulic separators...



High performance hydraulic separators provide three functions:

1. hydraulic separation
2. air separation
3. dirt separation



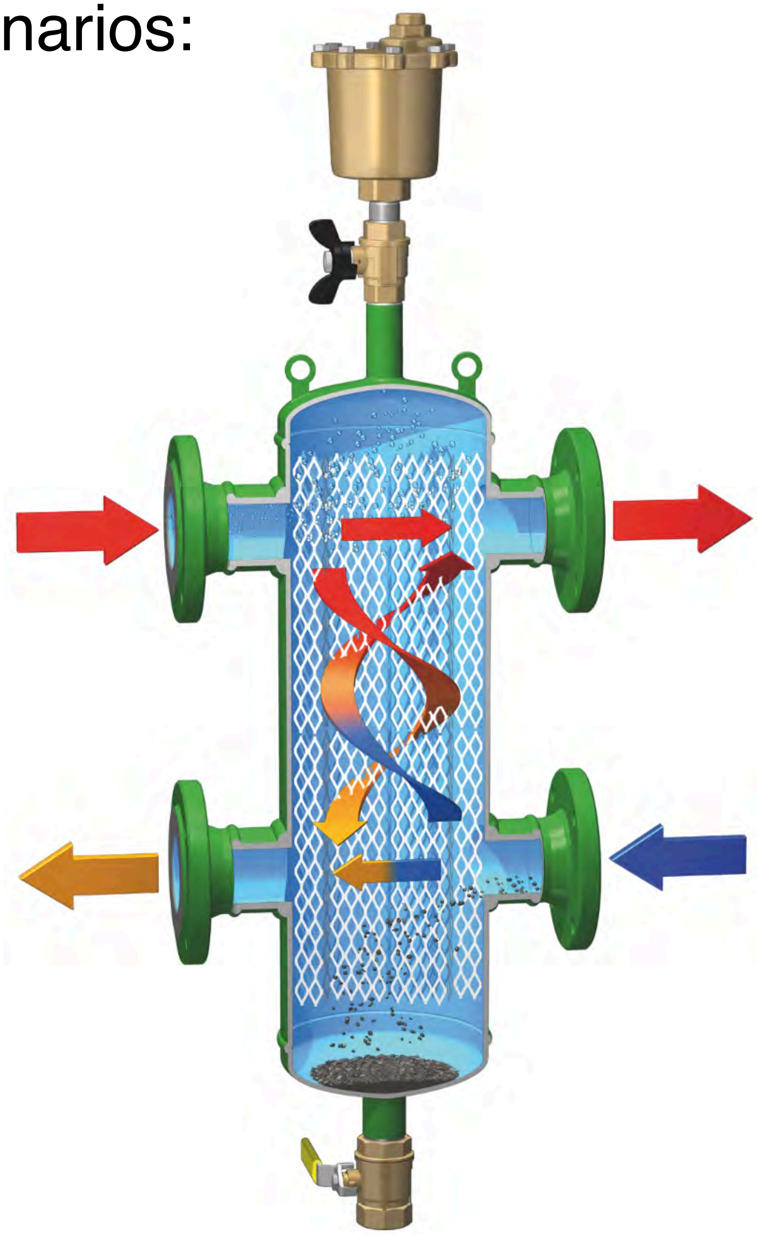
As the flow rates of the boiler circuit and distribution system change there are three possible scenarios:

1. Flow in the distribution system is equal to the flow in the boiler circuit.

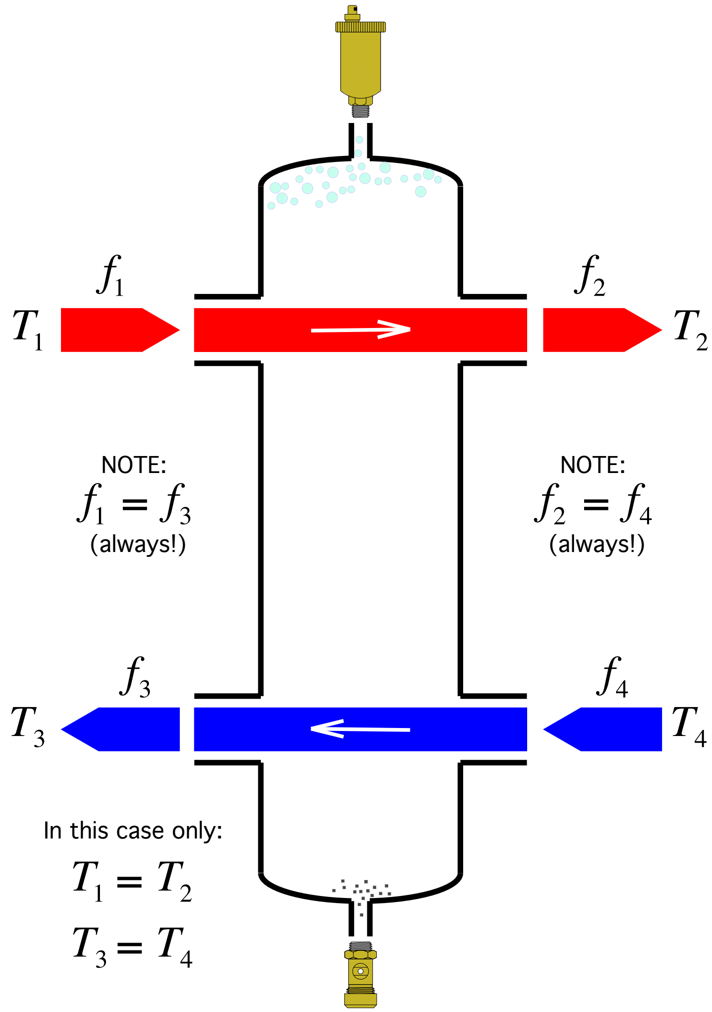
2. Flow in the distribution system is greater than flow in the boiler circuit.

3. Flow in the distribution system is less than flow in the boiler circuit.

Each case is governed by basic thermodynamic...

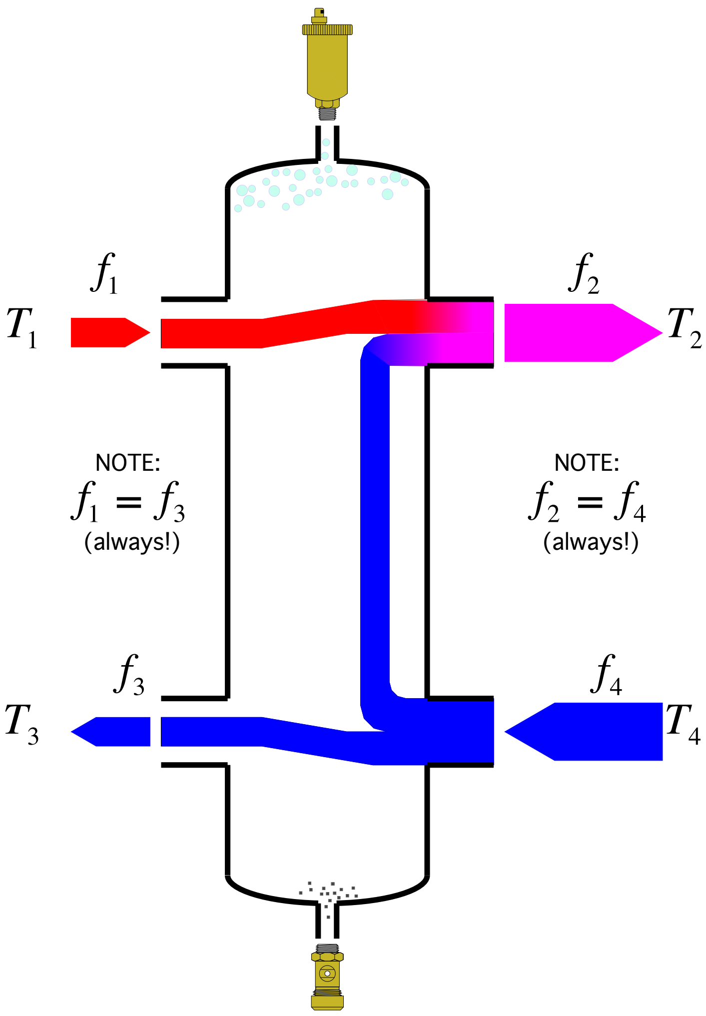


Case #1: Distribution flow equals boiler flow:



Very little mixing occurs because the flows are balanced.

Case #2: Distribution flow is greater than boiler flow:



The mixed temperature (T_2) supplied to the distribution system can be calculated with:

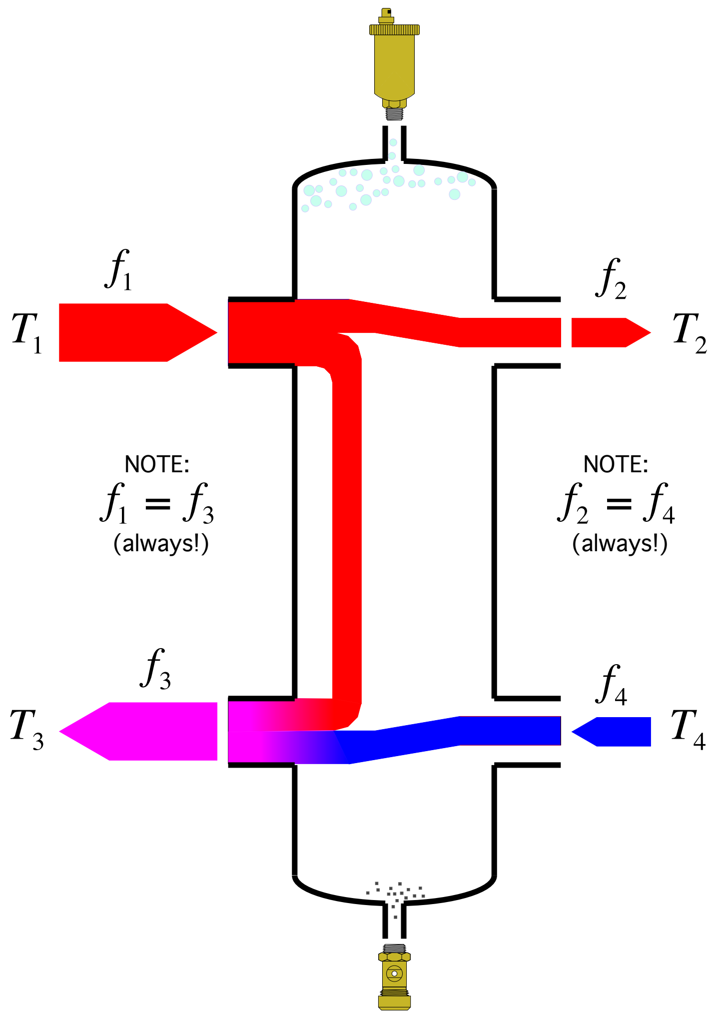
$$T_2 = \left(\frac{(f_4 - f_1)T_4 + (f_1)T_1}{f_4} \right)$$

Where:
f4 = flow rate returning from distribution system (gpm)
f1 = flow rate entering from boiler(s) (gpm)
T4 = temperature of fluid returning from distribution system (°F)
T1 = temperature of fluid entering from boiler (°F)

Mixing occurs within the hydraulic separator.

Case #3: Distribution flow is less than boiler flow:

Heat output is *temporarily* higher than current system load.



Heat is being injected faster than the load is removing heat.

The temperature returning to the boiler (T_3) can be calculated with:

$$T_2 = \left(\frac{(f_4 - f_1)T_4 + (f_1)T_1}{f_4} \right)$$

Where:
T3 = temperature of fluid returned to boiler(s) (°F)
f1 = flow rate entering from boiler(s) (gpm)
f2, f4 = flow rate of distribution system (gpm)
T1 = temperature of fluid entering from boiler (°F)
T4 = temperature of fluid returning from distribution system (°F)

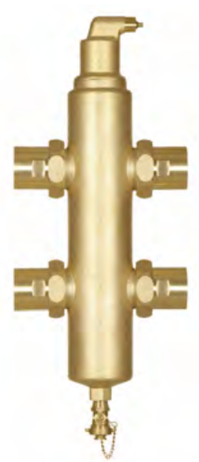
Mixing occurs within the hydraulic separator.

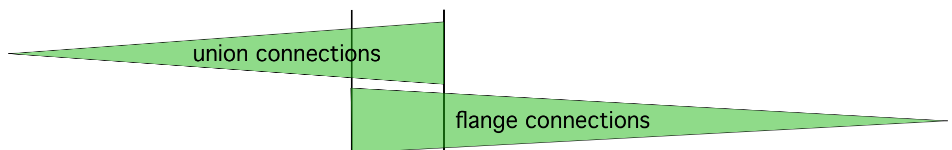
Sizing of Hydraulic Separators:

Hydraulic separators must be properly sized to provide proper hydraulic, air, and dirt separation. Excessively high flow rates will impede these functions.

The “size” of a hydraulic separator refers to the nominal piping size of the 4 side connections (not the diameter of the vertical barrel).

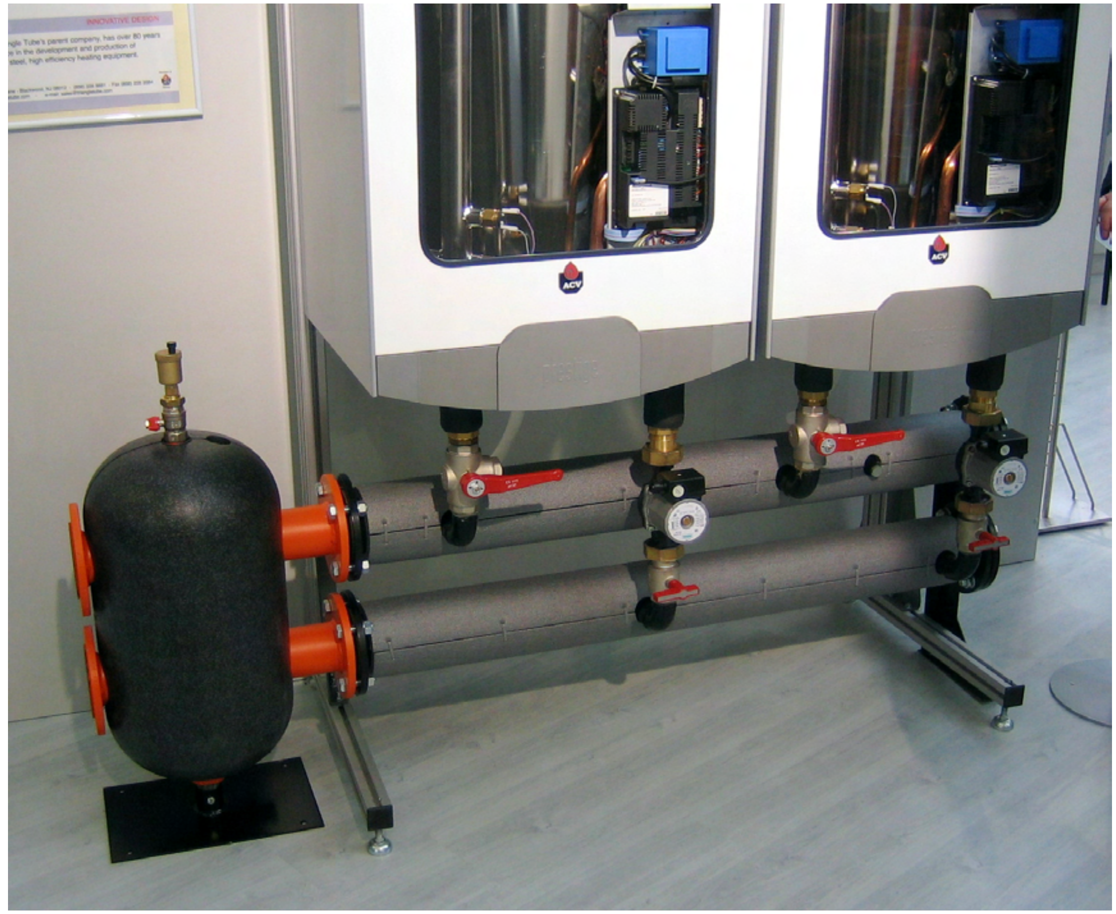
The piping connecting to the distribution side of the Hydro Separator should be sized for a flow of 4 feet per second or less under maximum flow rate conditions.





Pipe size of hydraulic separator	1”	1.25”	1.5”	2”	2.5”	3”	4”	6”
Max flow rate (GPM)	11	18	26	40	80	124	247	485

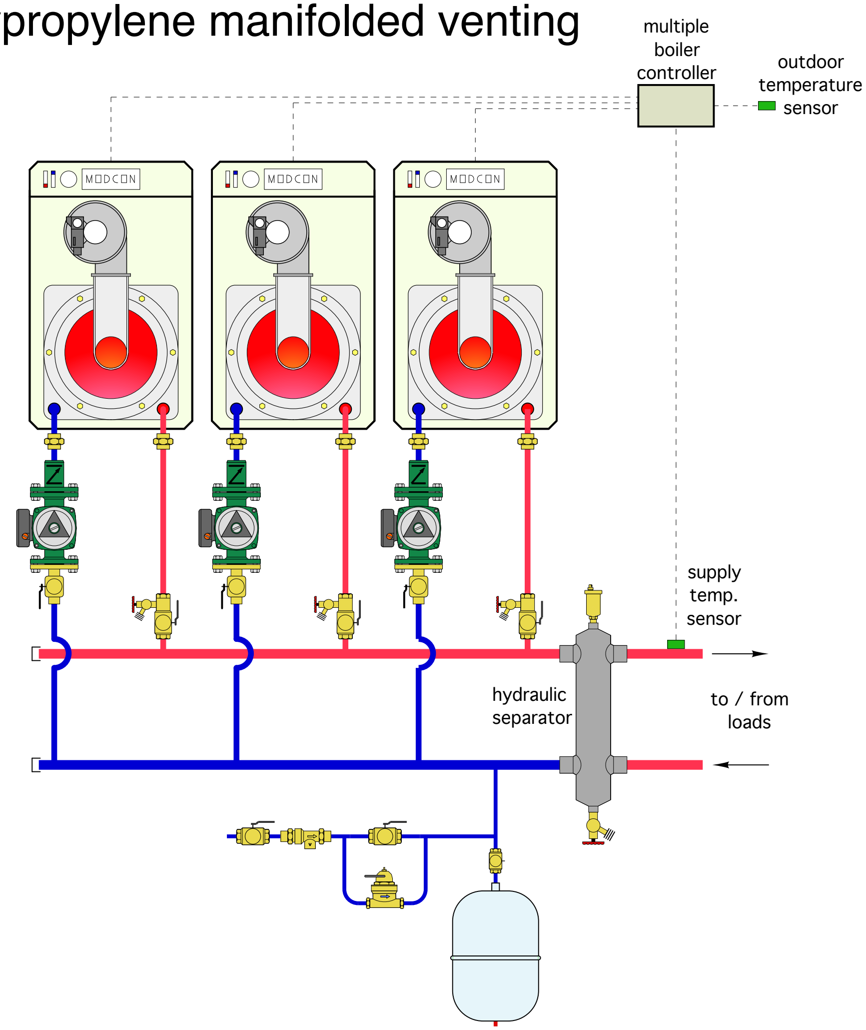
Typical European concepts for multiple mod/con installation:



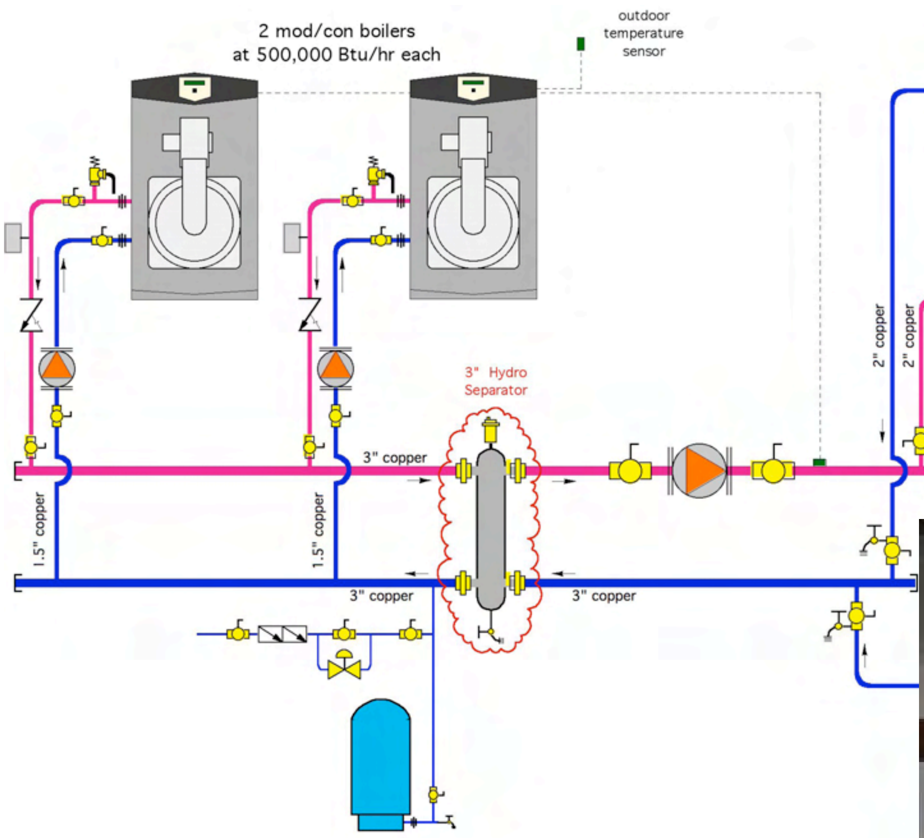
Typical European concepts for multiple mod/con installation:

What did you notice in common on those last two photos?

- Modular manifold system - could be expanded if necessary
- Hydraulic separator interface to system
- Pre-engineered racking systems
- individual circulators on each boiler
- Polypropylene manifolded venting



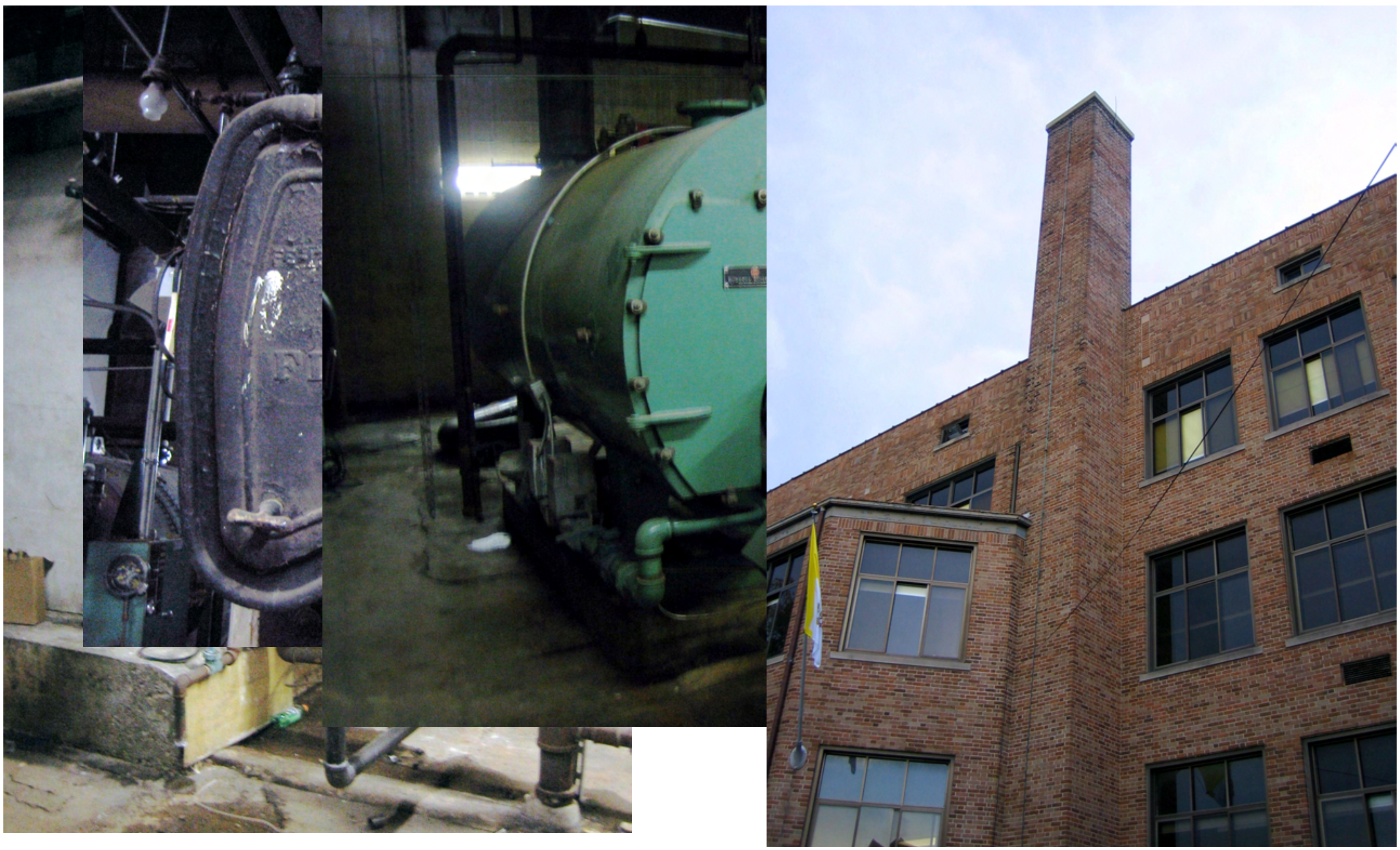
Example of Hydro Separator Installation in N
Magna Steel Corporation - Connecticut



Photos courtesy of Peter Gasperini - Northeast Radiant

Example of Hydro Separator Installation in Old System:

Because hydraulic separators remove sediment fromsystems they're ideal for applications where new boilers are retrofit to old distribution systems.



Example of Hydro Separator Installation in Old System:

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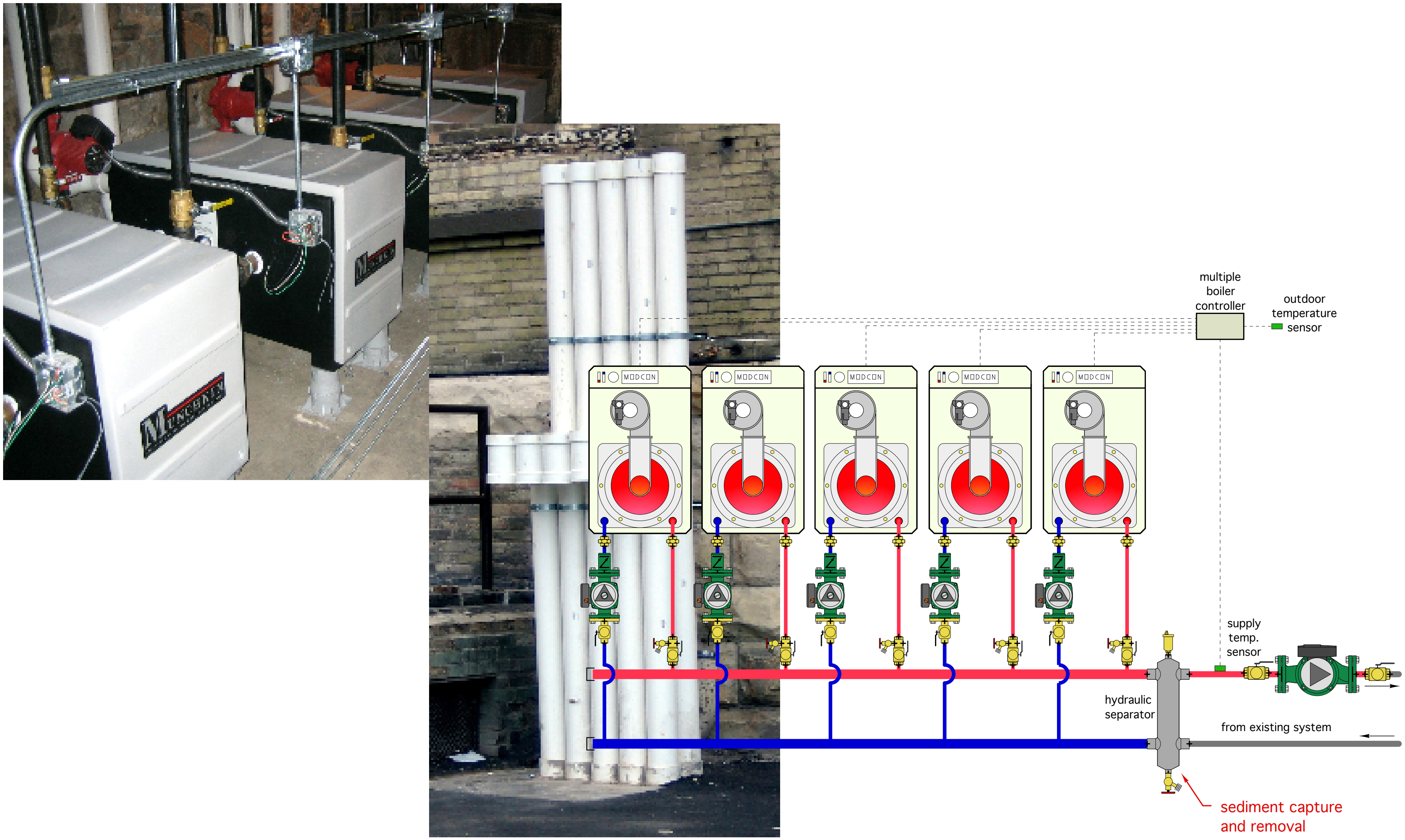
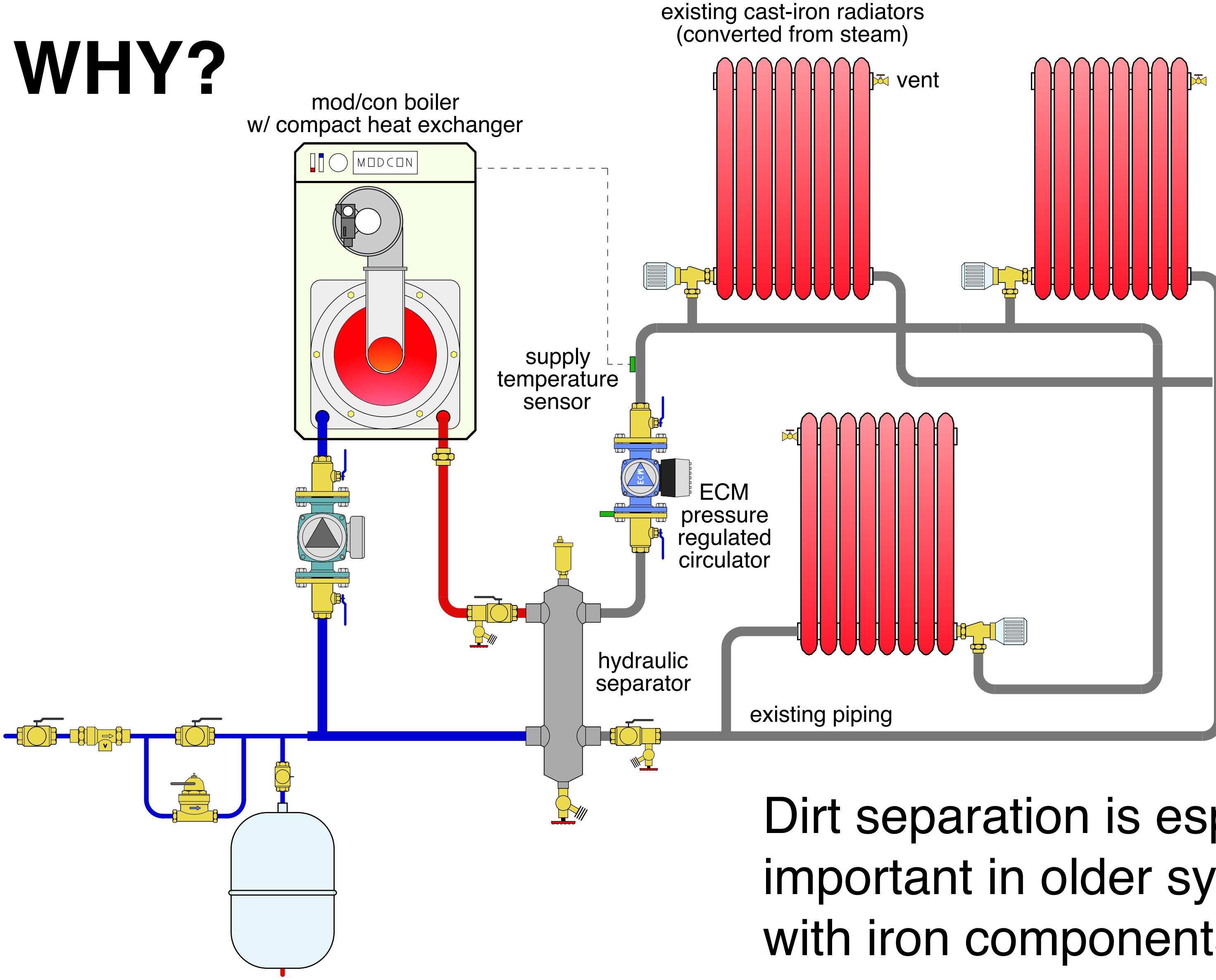


A hydraulic separator is a great way to interface a new mod/con boiler to a older “steam conversion” system.

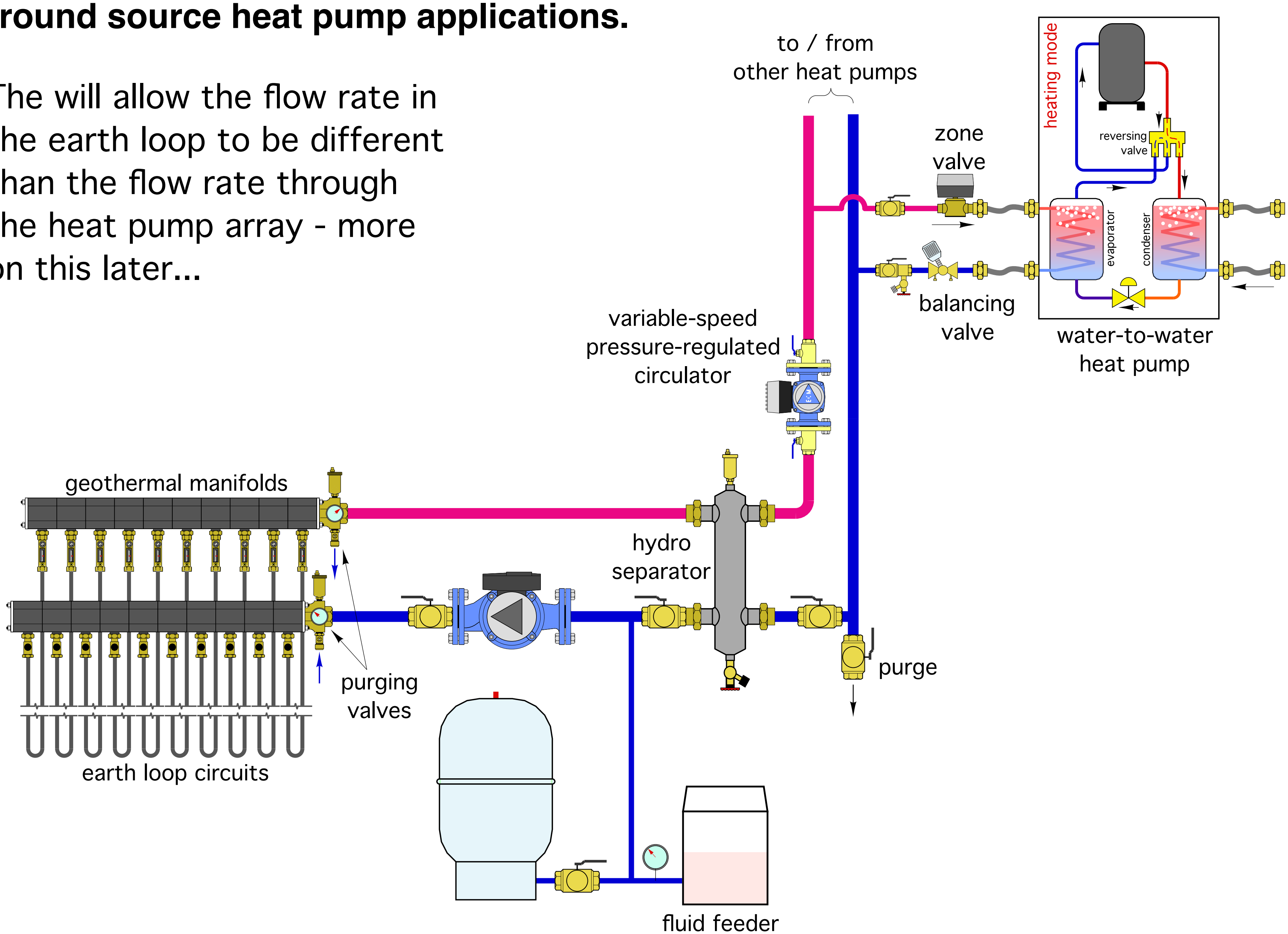
WHY?



Dirt separation is especially important in older systems with iron components.

Hydraulic Separators will likely become a key component in multiple ground source heat pump applications.

The will allow the flow rate in the earth loop to be different than the flow rate through the heat pump array - more on this later…

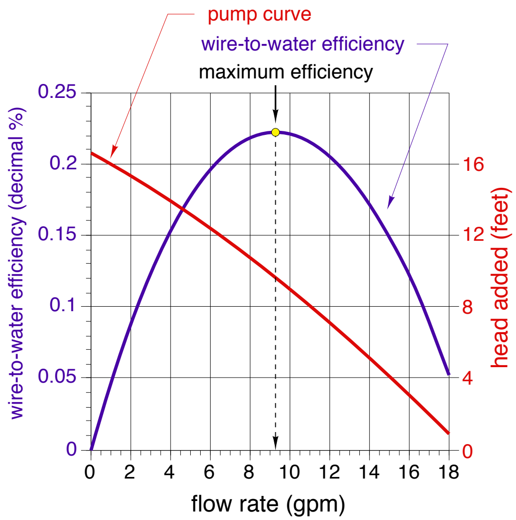


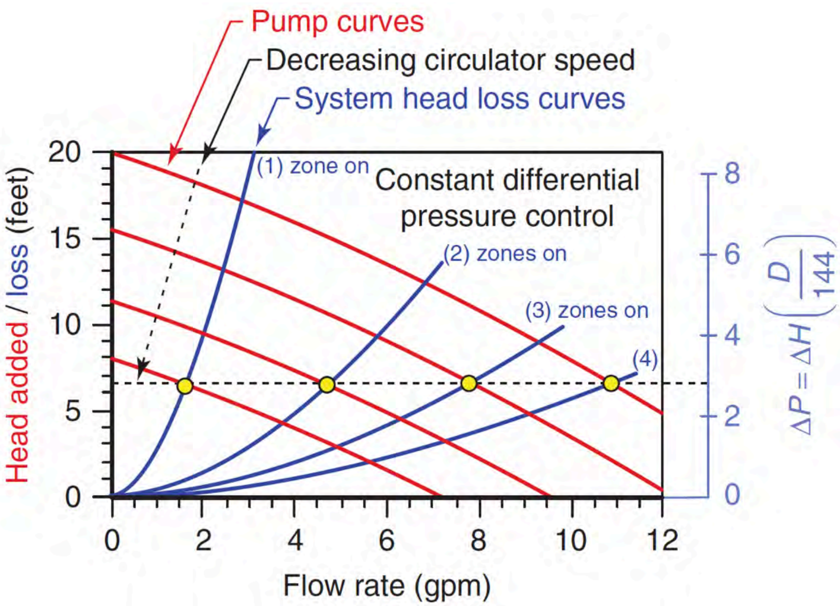
What's wrong with these installations?

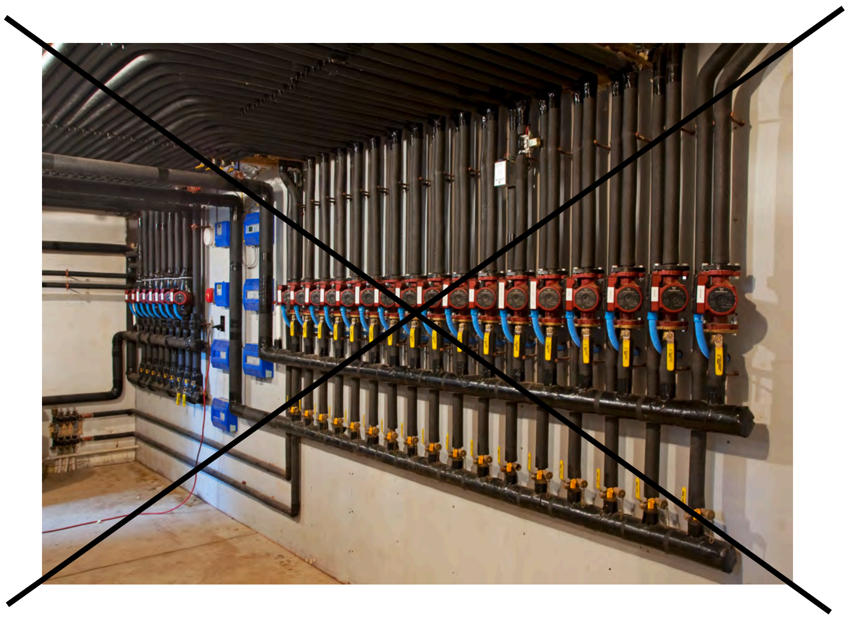
Answer: There is nothing to drive flow through the circuit on the left side of separator. The closely spaced tees are totally unnecessary.

Answer: There is no way this can function as a hydraulic separator. There's a reason that hydraulic separators have 4 side ports, and it's not so that 2 of them can be plugged.

Distribution Efficiency
& Low Power Pumping...

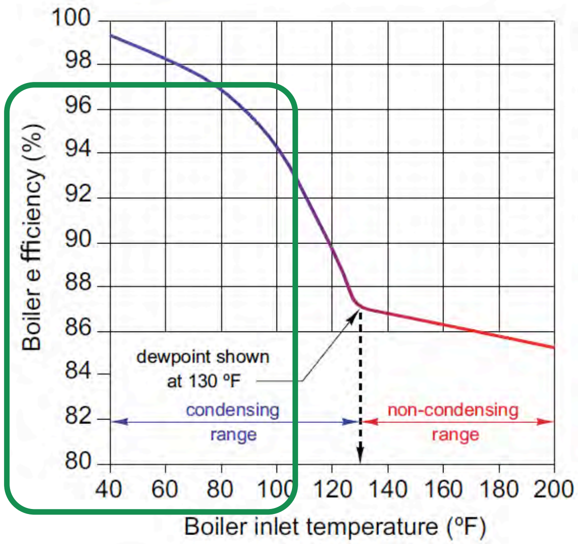






The North American Hydronics market has many "high efficiency" boilers

In the right applications these boilers have efficiencies in the 95+ range:



It may appear there isn't room for improving the efficiency of hydronic systems…

At least that's what people who focus *solely* on the boiler might conclude

For decades our industry has focused on *incremental improvements* in the thermal efficiency of heat sources.

At the same time we've largely ignored the hydraulic efficiency of the distribution system.

Those seeking high efficiency hydronic systems have to understand "**Its not always about the boiler!**"

The present situation:

What draws your attention in the photo below?

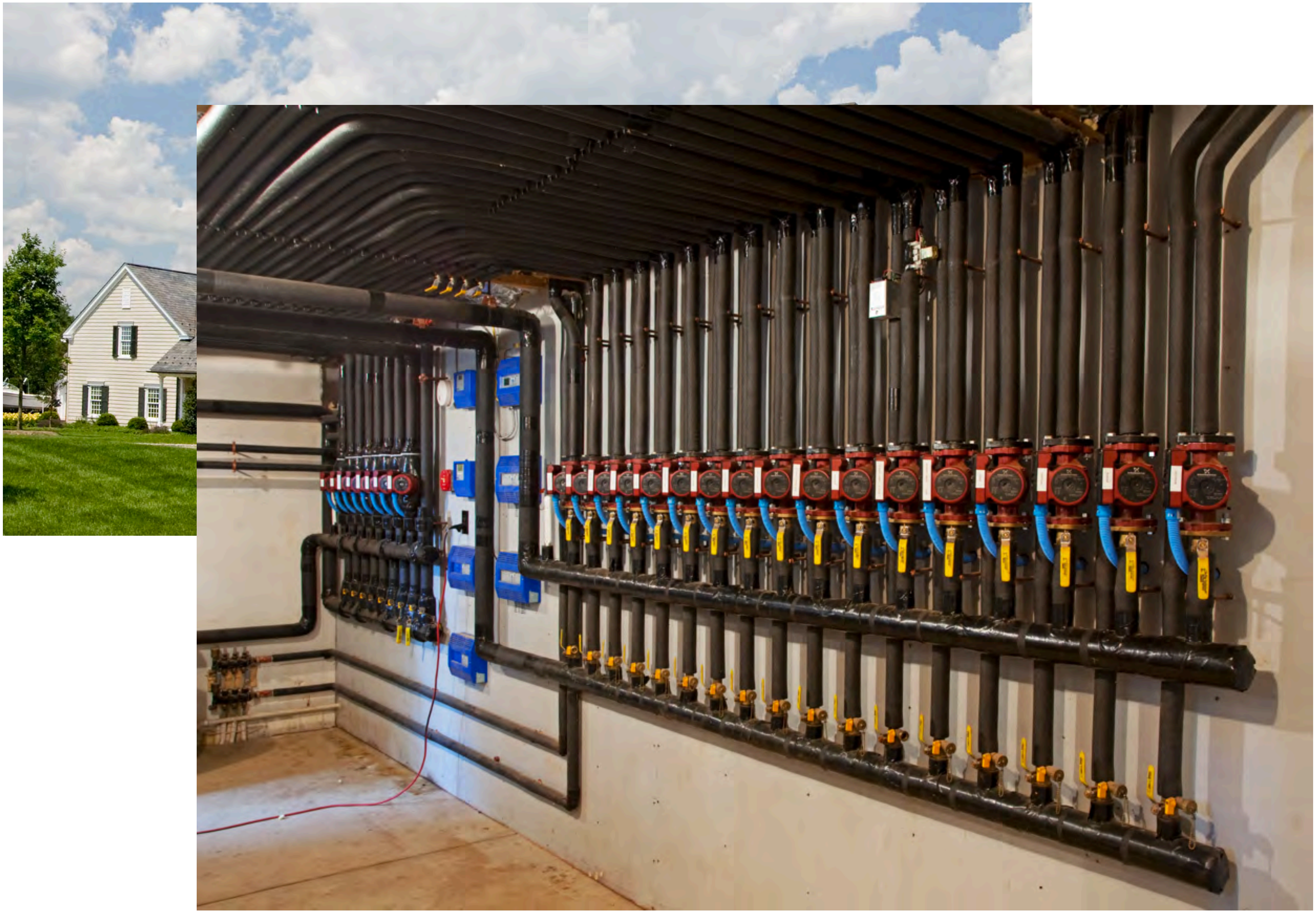
If all these circulators operate simultaneously (at design load) the electrical demand will be in excess of 5000 watts.

That's the heating equivalent of about 17,000 Btu/hr!

Here's another example...

Great "craftsmanship" - Wrong "concept"

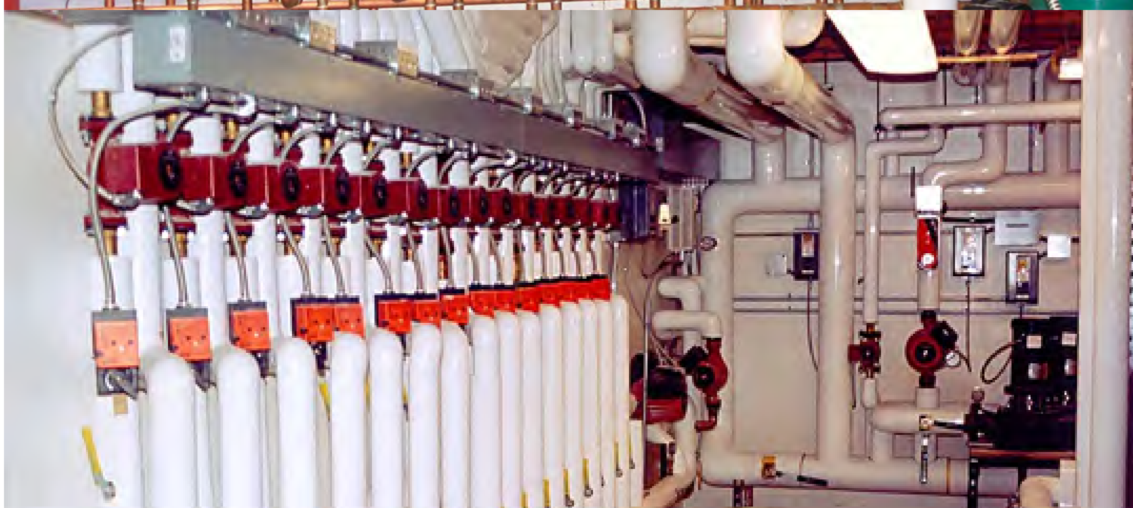
Here's another (award winning) example...



If you run out of wall space consider this installation technique...

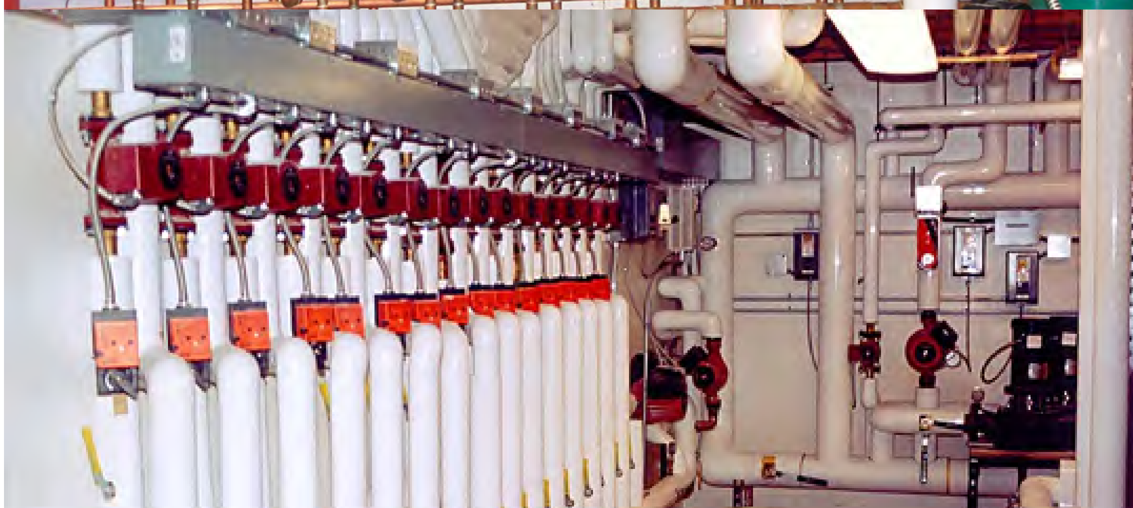
Notice the installer left provisions for additional circulators.

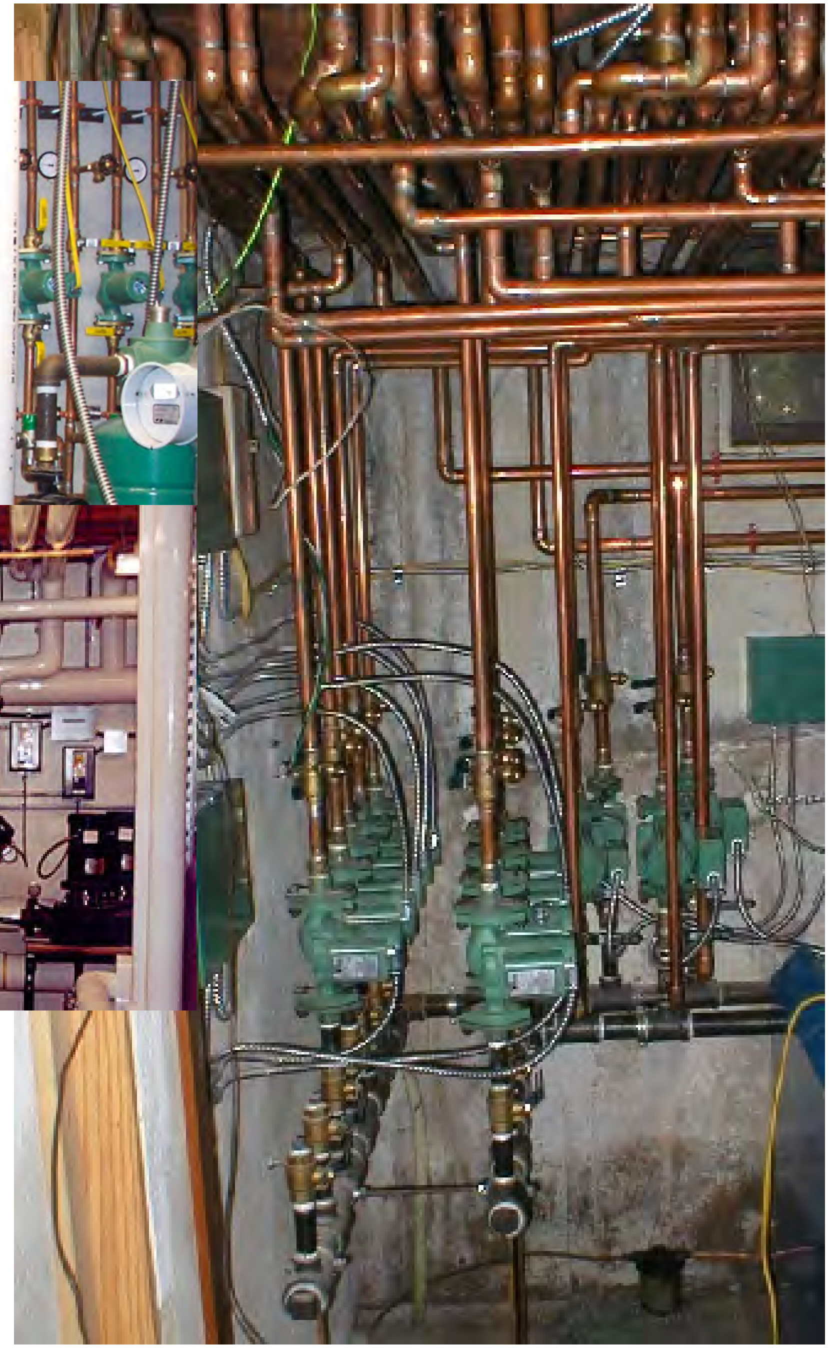
So what can you conclude from these photos?



Perhaps that it's <u>GOOD</u> to be in the circulator business these days!

You might also conclude that...





The North American hydronics industry tends to “overpump” its systems!

Just to be fair to the pump guys –
there is such a thing as overzoning with zone valves…

Although as an industry we pride ourselves on ultra high efficiency and "eco-friendly" heat sources, we…

Must look beyond the efficiency of only the heat source.

We need to look at the overall **SYSTEM efficiency**.

This includes the **thermal efficiency** of converting fuel in heated water AND the **distribution efficiency** of moving that water through the building.

This is important

So is this!

Defining DISTRIBUTION EFFICIENCY

$$\text{Efficiency} = \frac{\text{desired OUTPUT quantity}}{\text{necessary INPUT quantity}}$$

Distribution efficiency for a space heating system.

$$\text{distribution efficiency} = \frac{\text{rate of heat delivery}}{\text{rate of energy use by distribution equipment}}$$

Consider a system that delivers 120,000 Btu/hr at design load conditions using four circulators operating at 85 watts each. The distribution efficiency of that system is:

$$\text{distribution efficiency} = \frac{120{,}000\ \text{Btu/hr}}{340\ \text{watts}} = 353\ \frac{\text{Btu/hr}}{\text{watt}}$$

So is a distribution efficiency of 353 Btu/hr/watt good or bad?

To answer this you need something to compare it to.

Suppose a furnace blower operates at 850 watts while delivering 80,000 Btu/hr through a duct system. It delivery efficiency would be:

$$\text{distribution efficiency}=\frac{80{,}000\ \text{Btu/hr}}{850\ \text{watts}}=94\ \frac{\text{Btu/hr}}{\text{watt}}$$

<u>The hydronic system in this comparison has a distribution efficiency almost four times higher than the forced air system.</u>

Water is vastly superior to air as a conveyor belt for heat.

Room for Improvement…

A few years ago I inspected a malfunctioning hydronic heating system in a 10,000 square foot house that contained **40 circulators.**

Assume the average circulator wattage is 90 watts.

The design heating load is 400,000 Btu/hr

The distribution efficiency of this system at design load is:

$$\text{distribution efficiency} = \frac{400{,}000 \text{ Btu/hr}}{40 \times (90 \text{ watts})} = 111 \ \frac{\text{Btu/hr}}{\text{watt}}$$

Not much better than the previous forced air system at 94 Btu/hr/watt

Water Watts...

It's hard to say if the wattage of past or current generation circulators is "where it needs to be" without knowing the mechanical power needed to move fluid through a specific circuit.

$$w_m = 0.4344 \times f \times \Delta P$$

Where:
W_m = mechanical power required to maintain flow in circuit (watts)
f= flow rate in circuit (gpm)
ΔP = pressure drop along circuit (psi)
0.4344 = units conversion factor

Example: How much mechanical power is necessary to sustain a flow of 180 ºF water flows at 5 gpm through a circuit of 3/4" copper tubing having an equivalent length of 200 feet?

Solution: The pressure drop associated with this head loss is 3.83 psi.

Putting these numbers into the formula yields:

$$w_m = 0.4344 \times f \times \Delta P = 0.4344 \times 5 \times 3.83 = 8.3 watts$$

That's quite a bit lower than the electrical wattage of even the smallest currently-available circulator. Why?

Because it's only the <u>mechanical wattage</u> required (power dissipation by the fluid) - <u>not the electrical input wattage</u> to the circulator's motor.

The ratio of the mechanical wattage the impeller imparts to the water divided by the electrical input wattage to operate the motor is called wire-to-water efficiency.

$$n_{w/w} = \frac{w_m}{w_e}$$

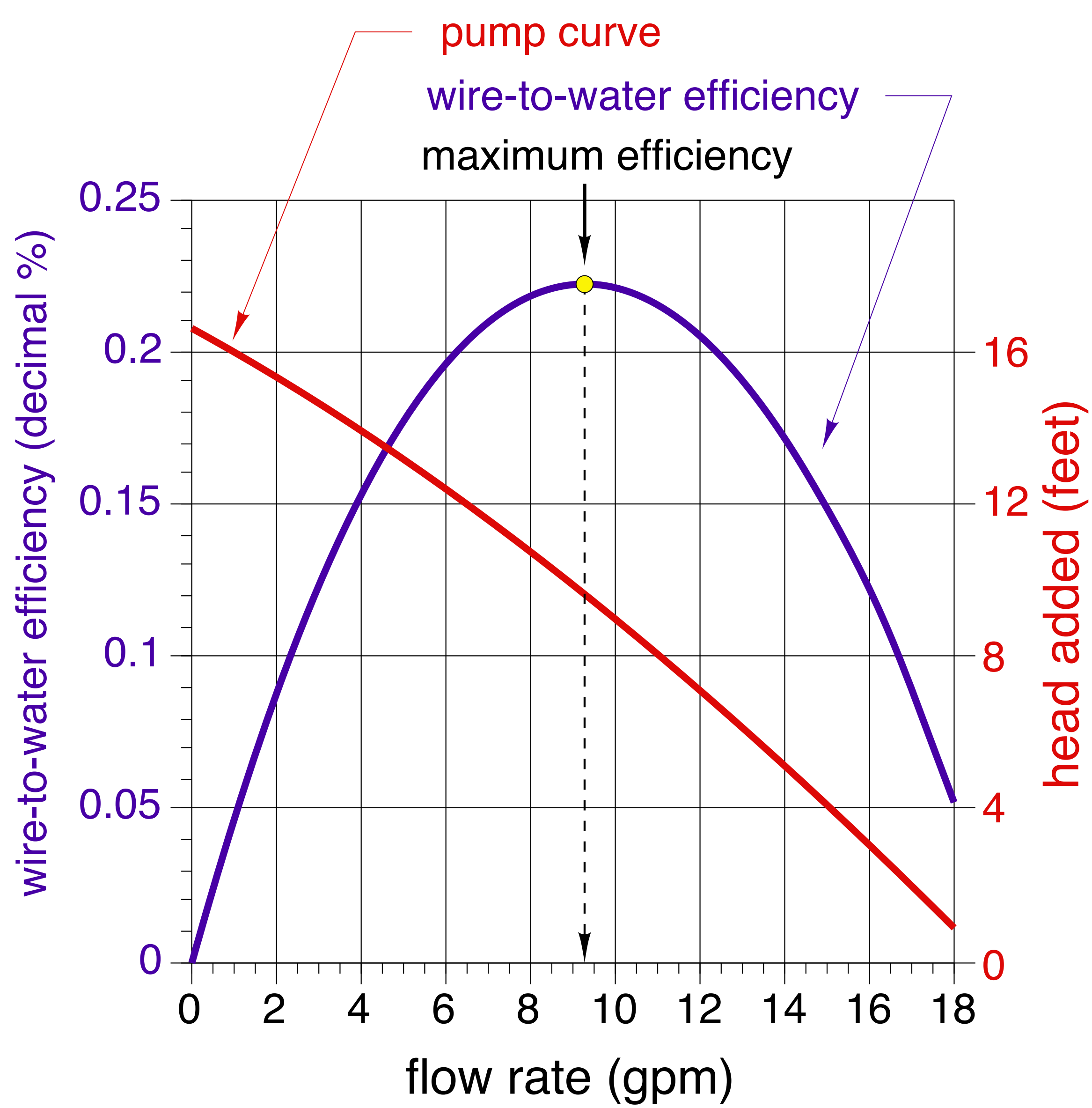
Where:

$n_{w/w}$ = wire-to-water efficiency of the circulator (decimal %)

w_m = mechanical power transferred to water by impeller (watts)

w_e = electrical power input to motor (watts)

If you take operating data for a typical 1/25 hp fixed-speed wet rotor circulator and plug it into this formula the efficiency curve looks as follows:



The electrical wattage needed by the circulator is:

$$w_e = \frac{0.4344 \times f \times \Delta P}{\boxed{n_{w/w}}}$$

A current-generation wet-rotor circulator has a maximum wire-to-water efficiency in the range of 25 percent. If we put the data from previous example into this formula we get the electrical wattage required to maintain flow in the circuit.

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}} = \frac{0.4344 \times 5 \times 3.83}{0.25} = 33.2 watts$$

Consider that a flow of 5 gpm in a circuit with a 20 ºF temperature drop is moving about 50,000 Btu/hr, and the electrical power to "run the conveyor belt" according to the last calculation is 33.2 watts. The distribution efficiency of such a circuit is:

$$n_d = \frac{Q}{w_e} = \frac{50{,}000\,Btu/hr}{33.2\,watt} = 1506\,\frac{Btu/hr}{watt}$$

Compare this to a 4-ton rated **geothermal water-to-air heat pump** delivering 48,000 Btu/hr using a blower operating on 1080 watts. The distribution efficiency of this delivery system is:

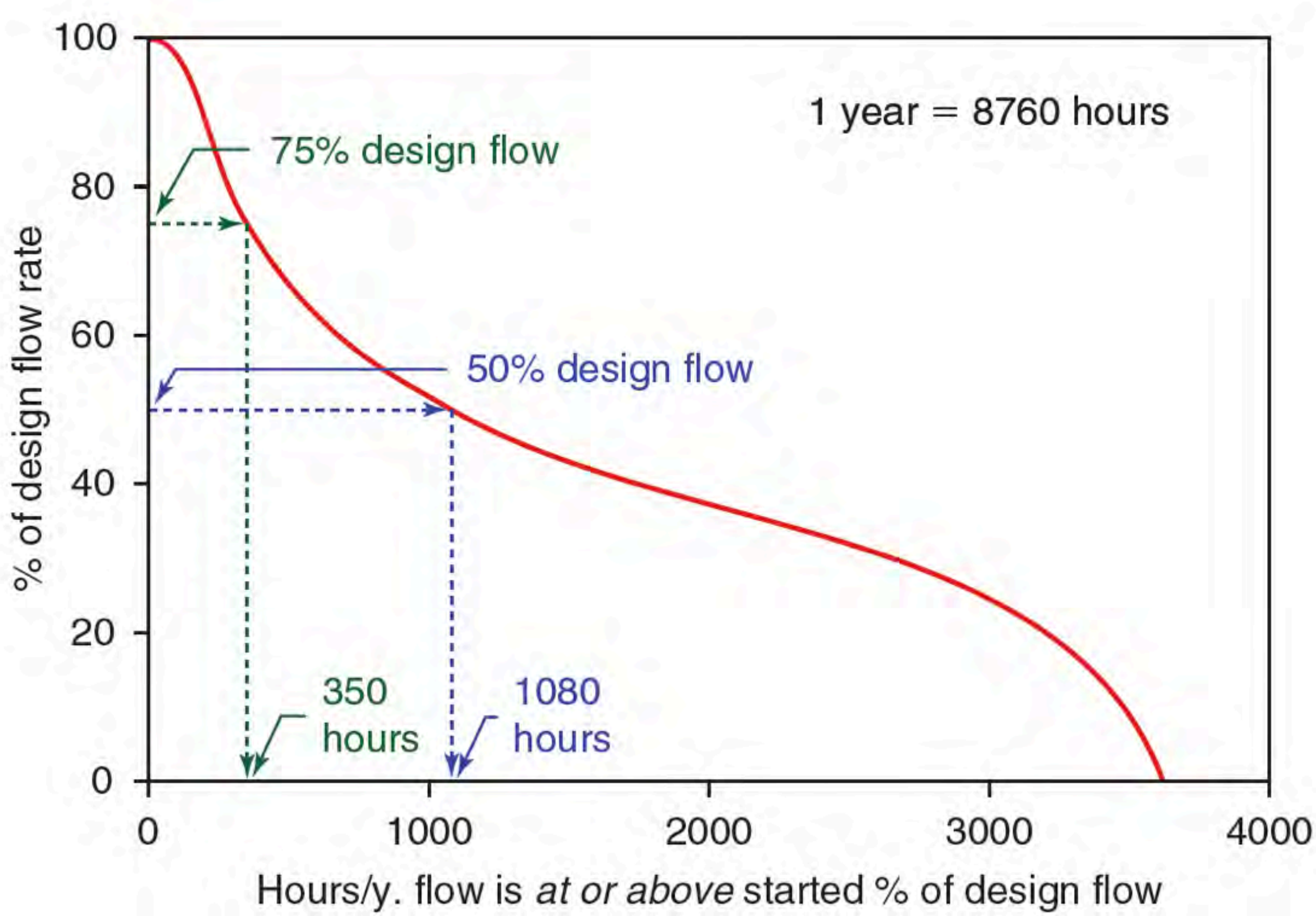
$$n_d = \frac{Q}{w_e} = \frac{48{,}000\,Btu/hr}{1080\,watt} = 44.4\,\frac{Btu/hr}{watt}$$

These numbers mean that the hydronic system delivers heat to the building using only 2.9 percent (e.g. 44.4/1506) of the electrical power required by the forced air delivery system.

With good design it's possible to achieve distribution efficiencies > 3000 Btu/hr/watt

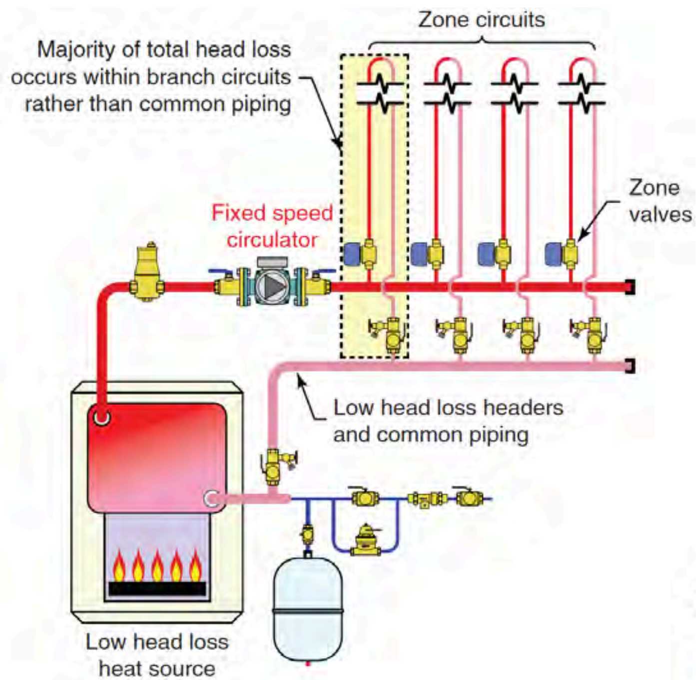
<u>**This will become increasingly important in low energy and net zero buildings...**</u>

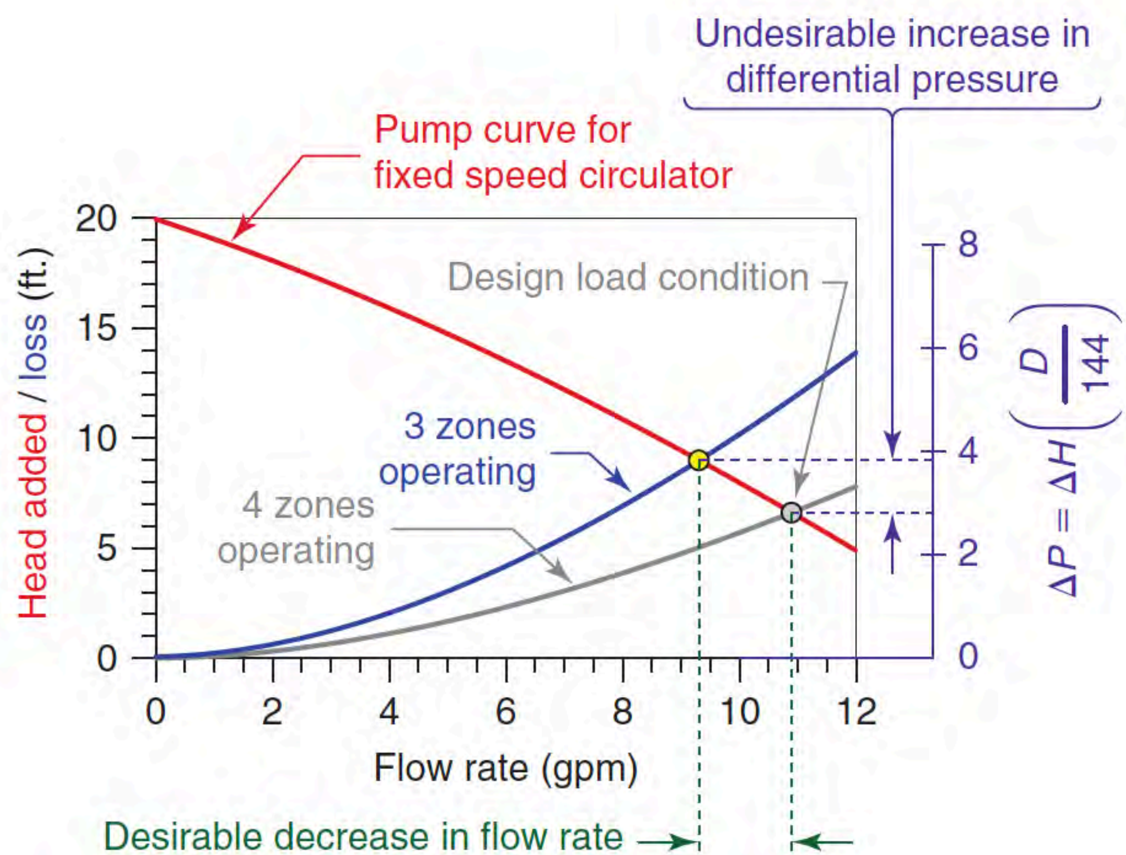
This graph shows the relationship between system flow rate vs. operating hours for a typical Northern climate.



Recognizing that partial flow is common, circulator engineers have developed "intelligent" operating algorithms for variable speed circulators.

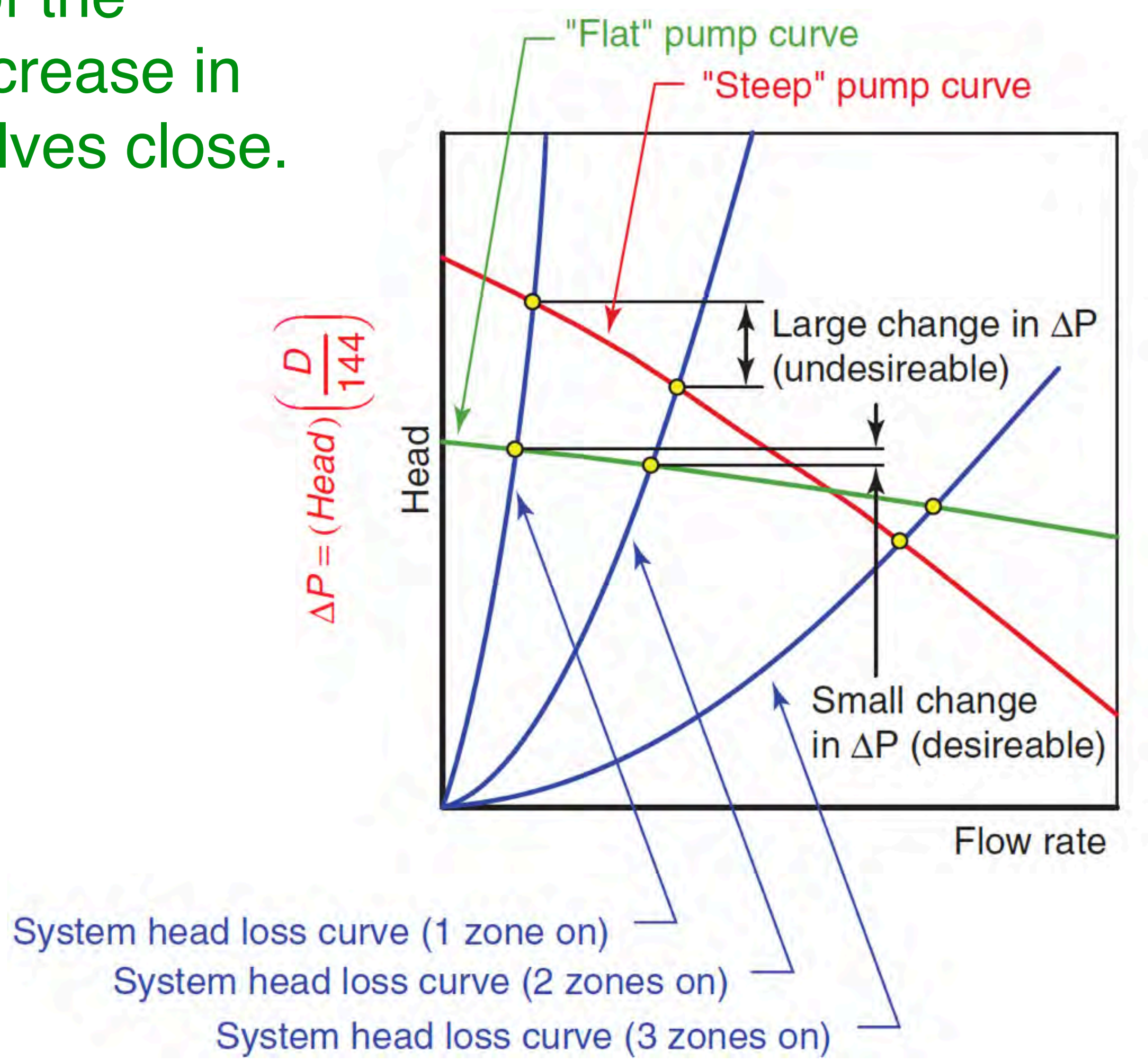
What happens when a zone valve closes?





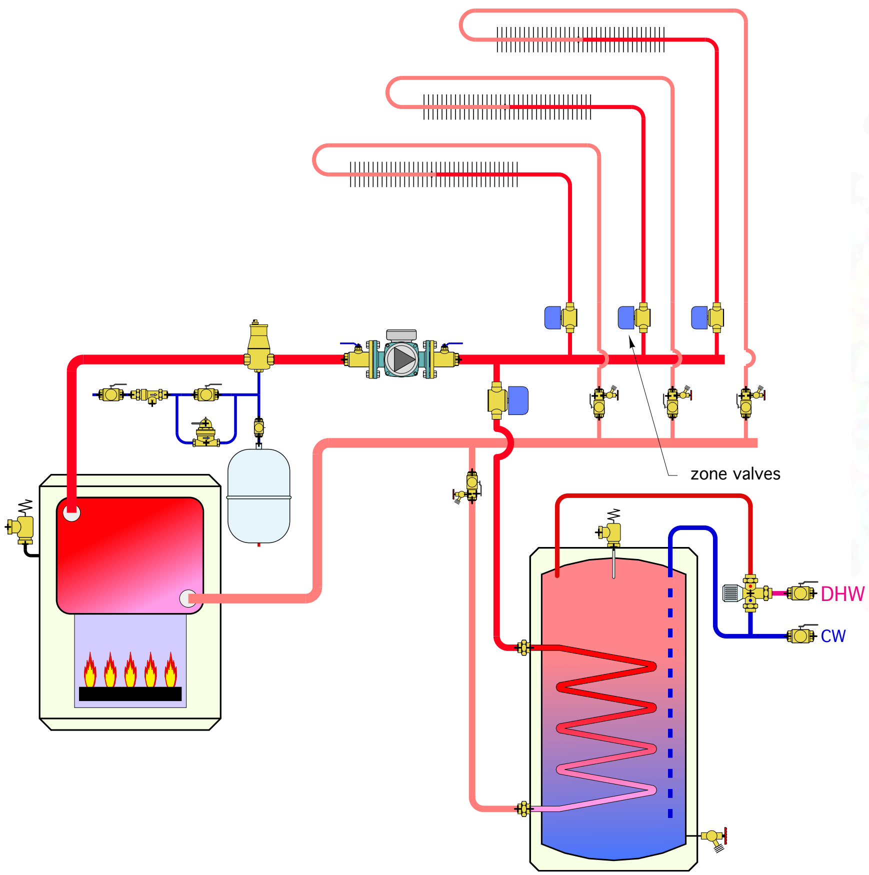
Applying ΔP Circulators

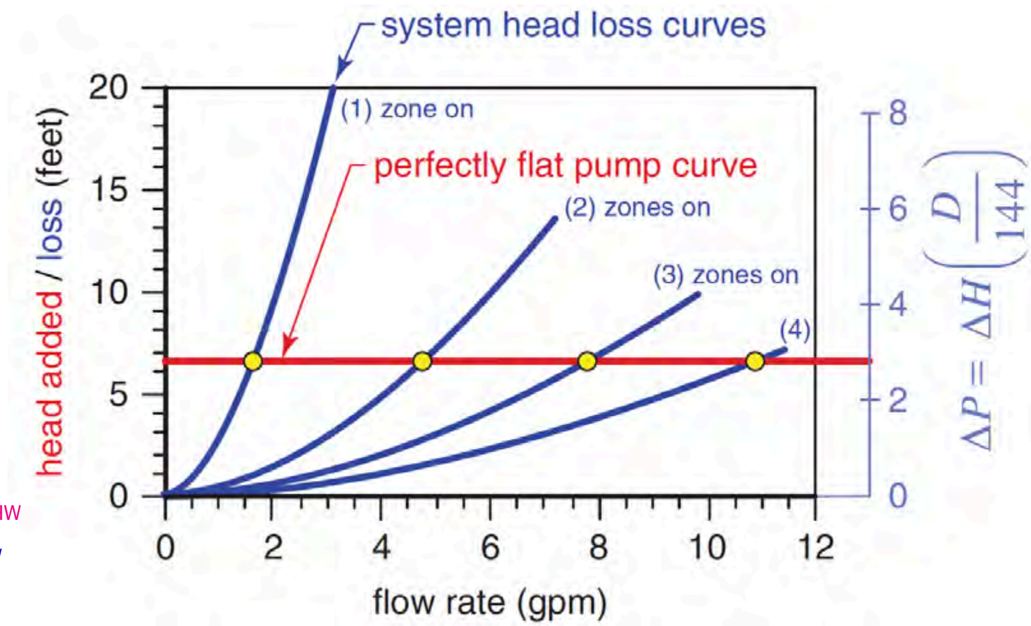
Flat pump curves produce less of the undesirable increase in ΔP as zone valves close.



What would be the **ideal** pump curve for a hydronic system using valve based zoning?

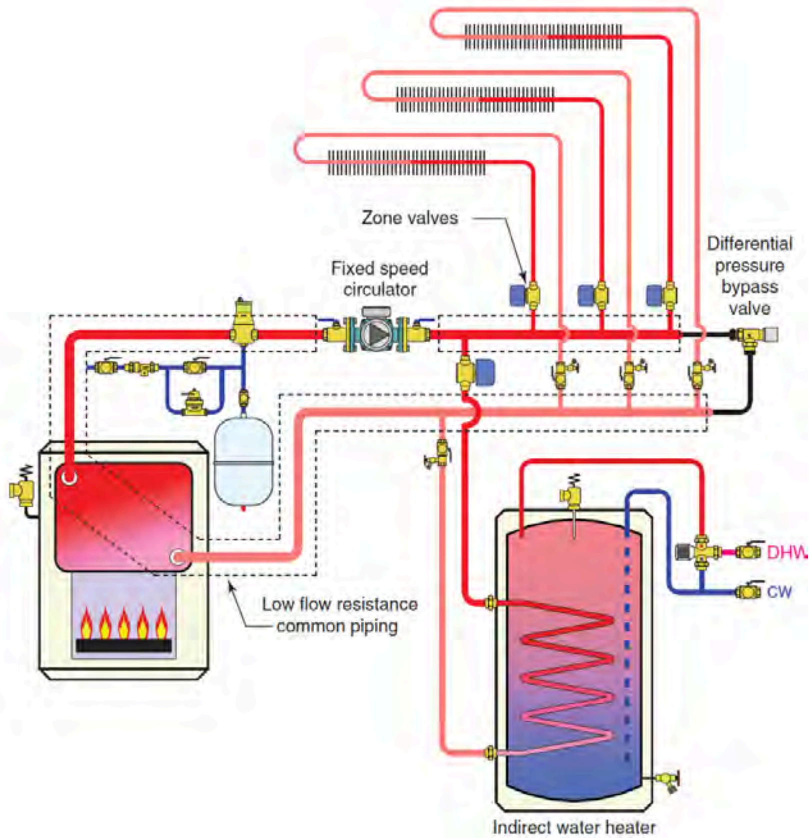
Answer: a perfectly flat pump curve

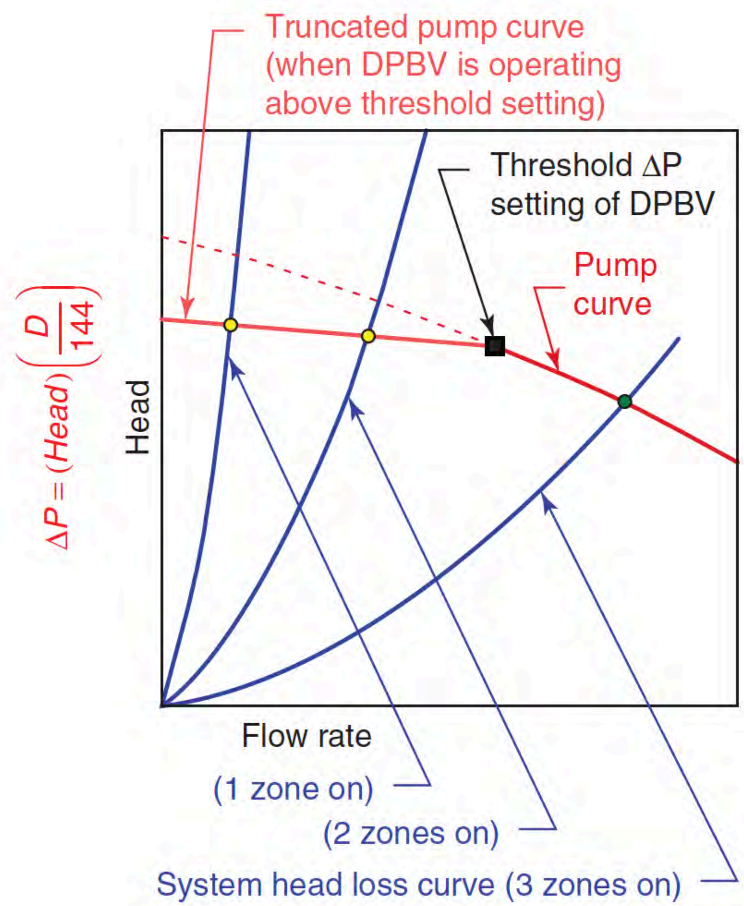




A perfectly flat pump curve would all steady flow rate in every zone circuit, regardless of which other zones are on.

Approximating a flat pump curve with ΔP bypass valve

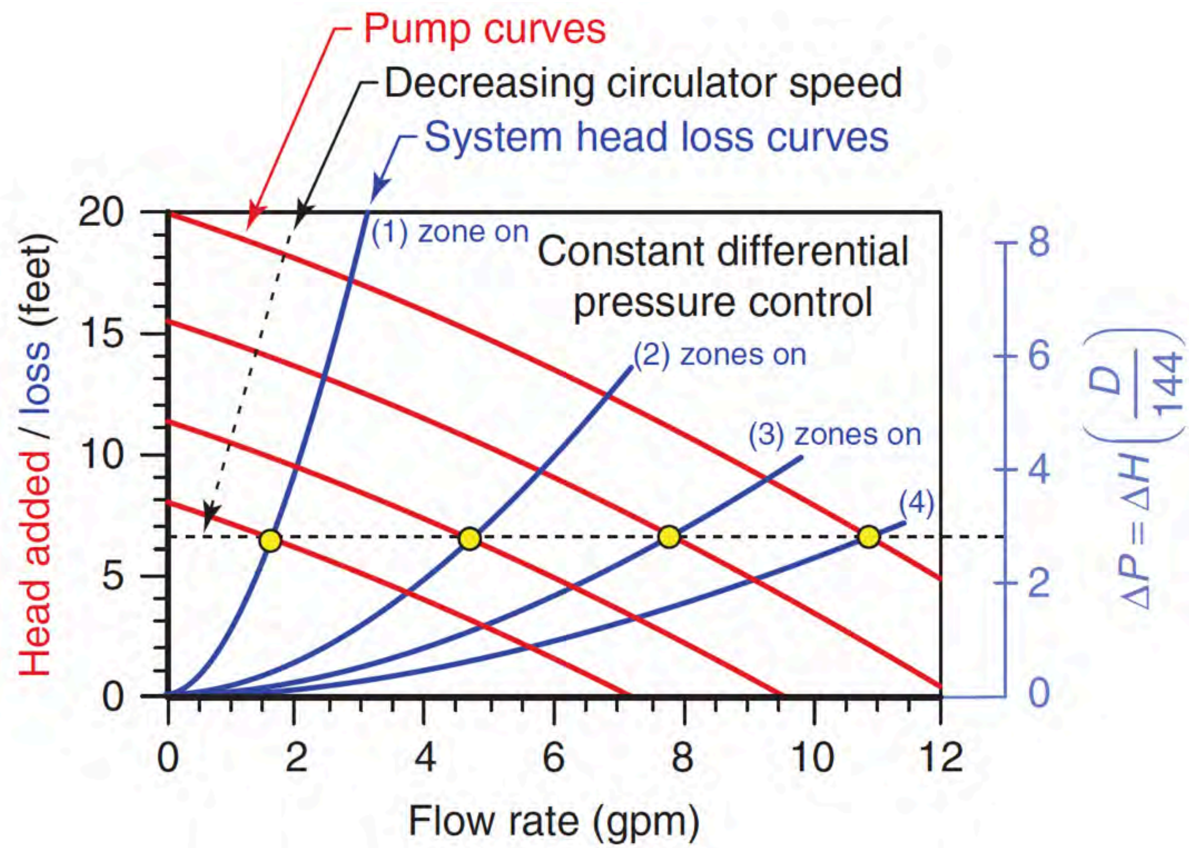




A ΔP bypass valve helps limit changes in differential pressure, but does so “parasitically” by throttling away head energy

Approximating a flat pump curve with ΔP bypass valve

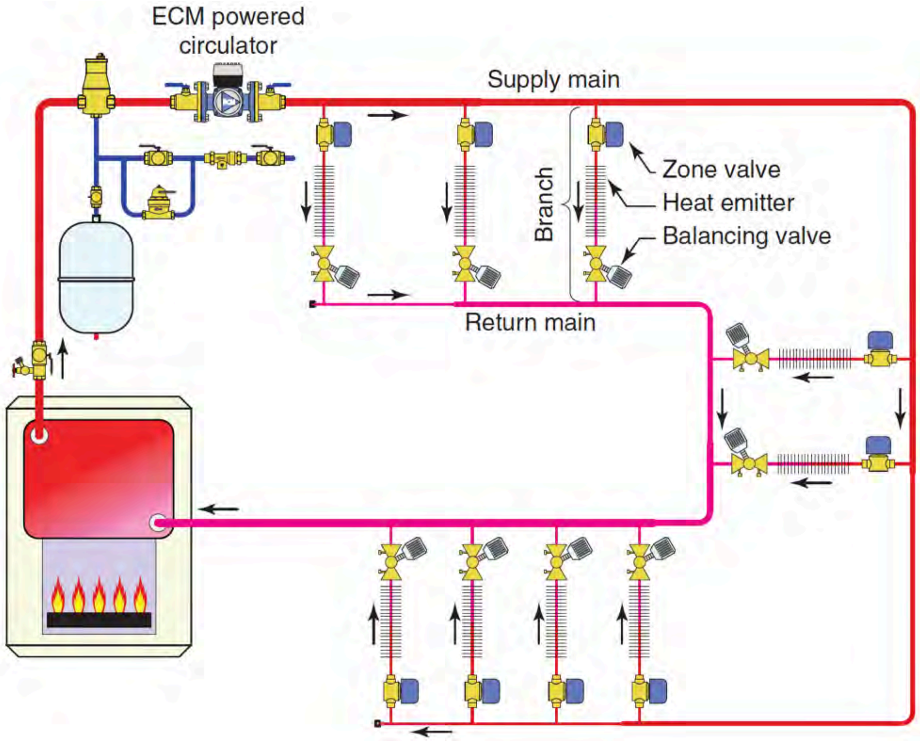
By varying the speed of the circulator it is possible to produce the same “net” effect as would be produced by a perfectly flat pump curve.

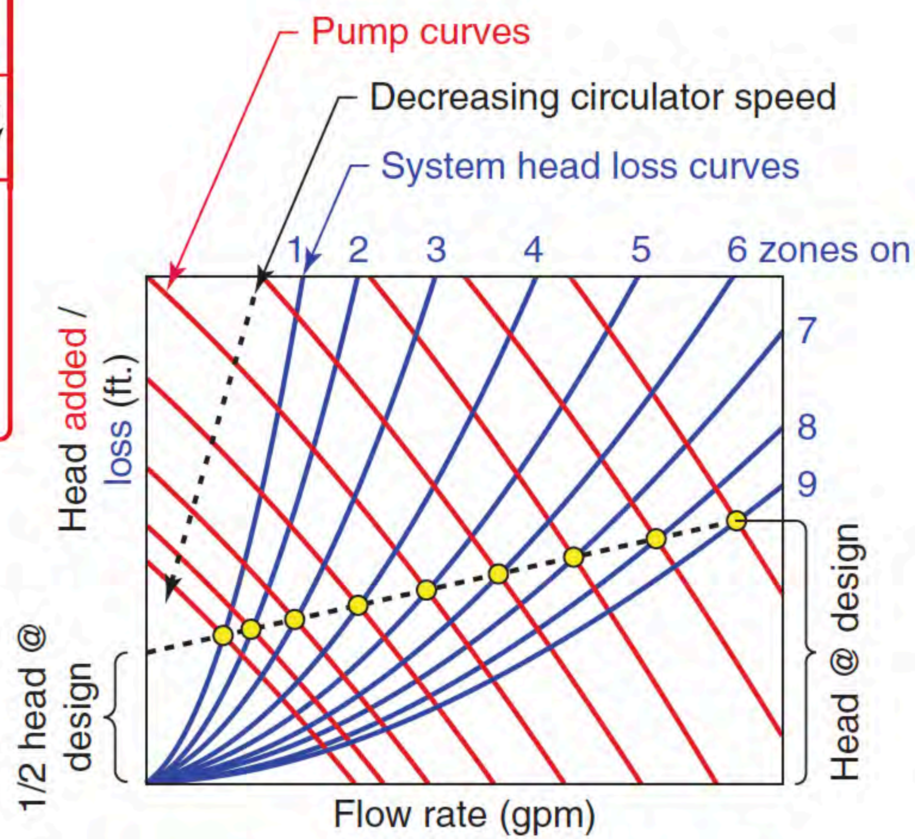


This is called
CONSTANT DIFFERENTIAL PRESSURE CONTROL

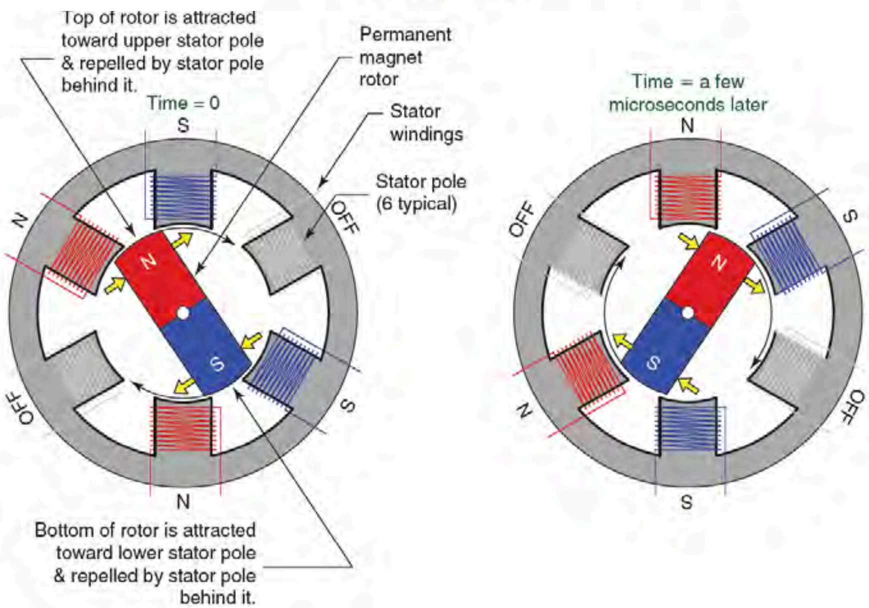
PROPORTIONAL DIFFERENTIAL PRESSURE CONTROL

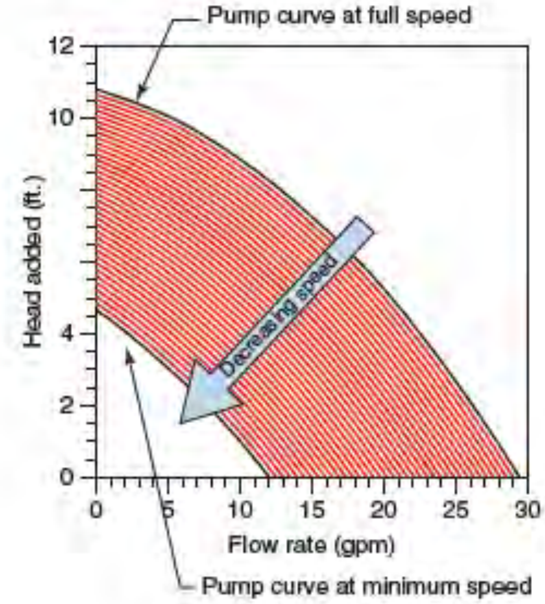
This method is best for systems where the heat source and/or "mains" piping leading to the load circuits dissipate a substantial portion of the circulator head.



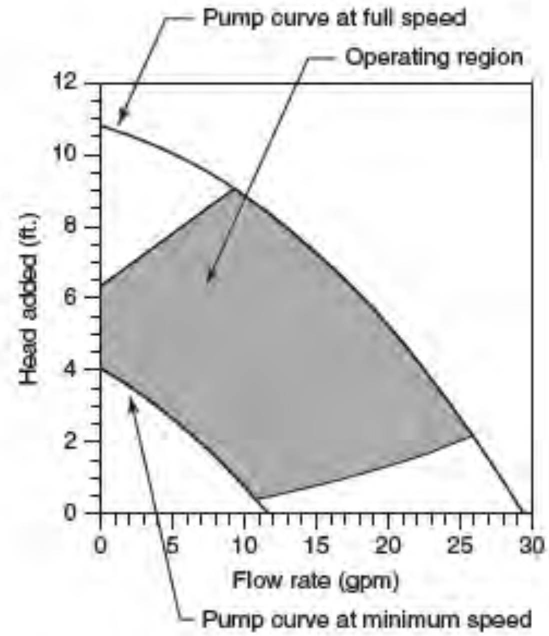


How does a ECM Circulator work?





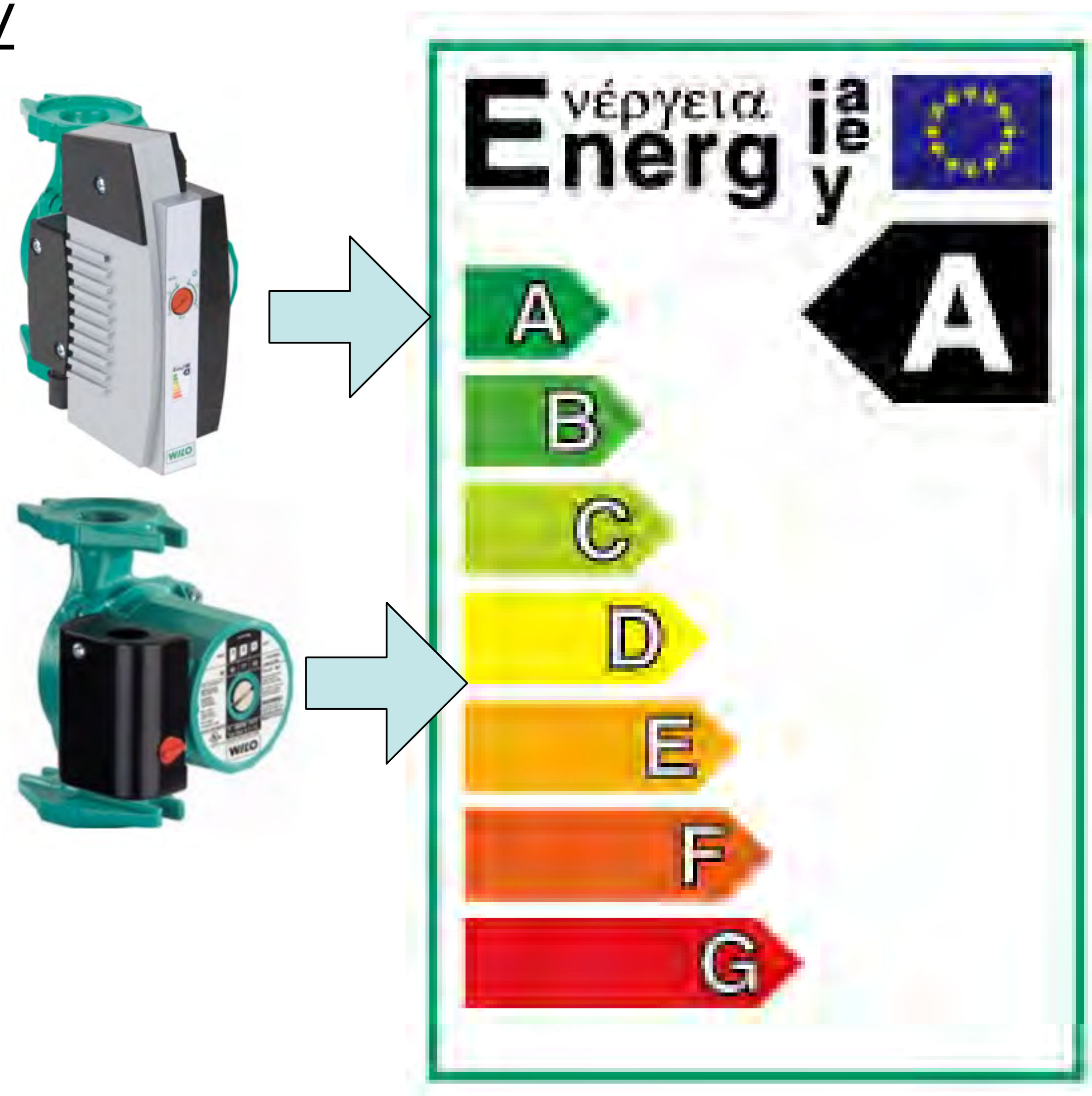
(a)



(b)

Current European circulator rating system

<u>All these circulators rated “A” on the energy labeling system from Europump (European Association of Pump Manufacturers).</u>



Single or multi-speed wet-rotor circulators like those commonly used in North America would be rated “D” or “E” on this scale.

Small ECM circulators now available in North America

Grundfos Alpha: Provides constant and proportional differential pressure and three fixed speed settings. 6-50 watt electrical input.

Wilo Stratos ECO 16F: Provide constant and proportional differential pressure. 5.8-59 watt electrical input.

Bell & Gossett ECOCIRC, Provides manual adjustable speed setting (VARIO model), and proportional differential pressure (AUTO model). 5-60 watt electrical input.

Taco Bumblebee Temperature based speed control. 9-42 watts electrical input

Armstrong COMPASS Provides constant and proportional differential pressure and three fixed speed settings. 3-45watt electrical input.

Circulators

high efficiency ECM Circulators

Larger ECM circulators now available in US

Wilo STRATOS circulators

Grundfos MAGNA

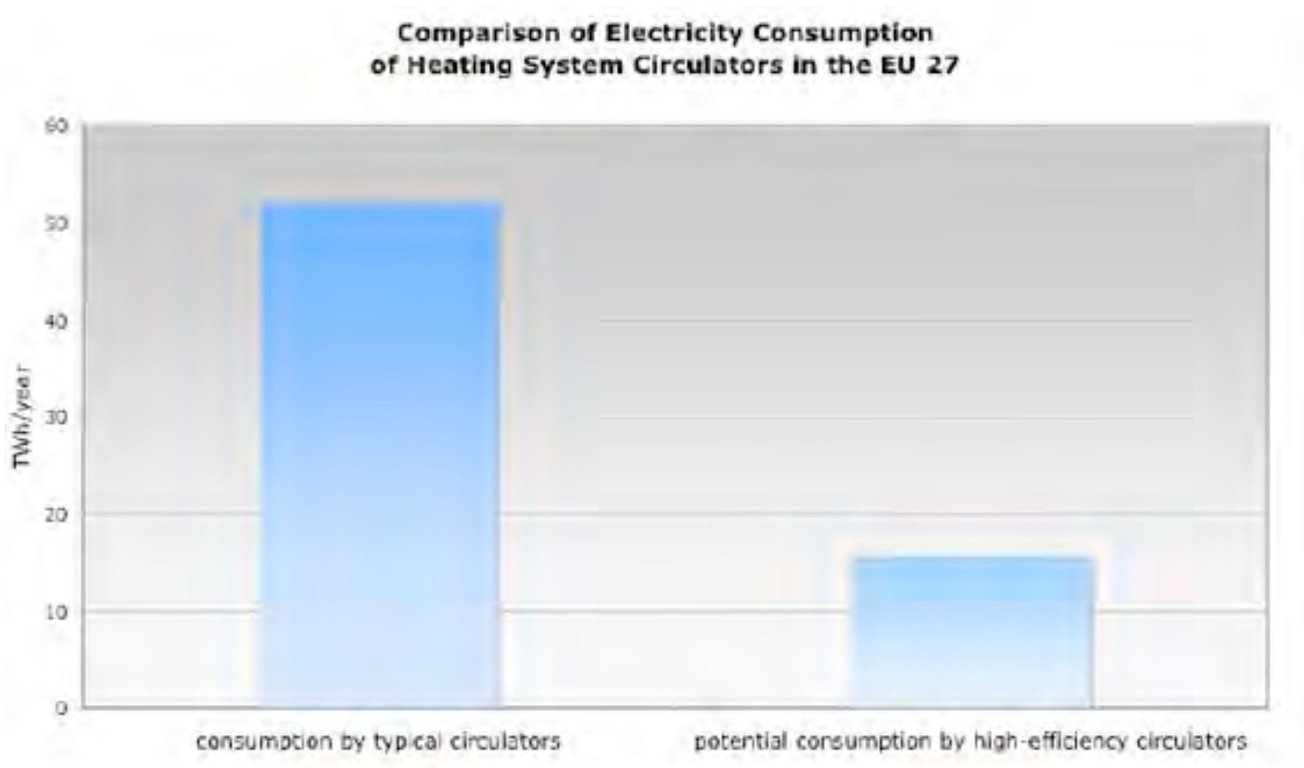
Taco Viridian

Heads to 45 feet,
flows to 345 gpm
power inputs to 1600 watts

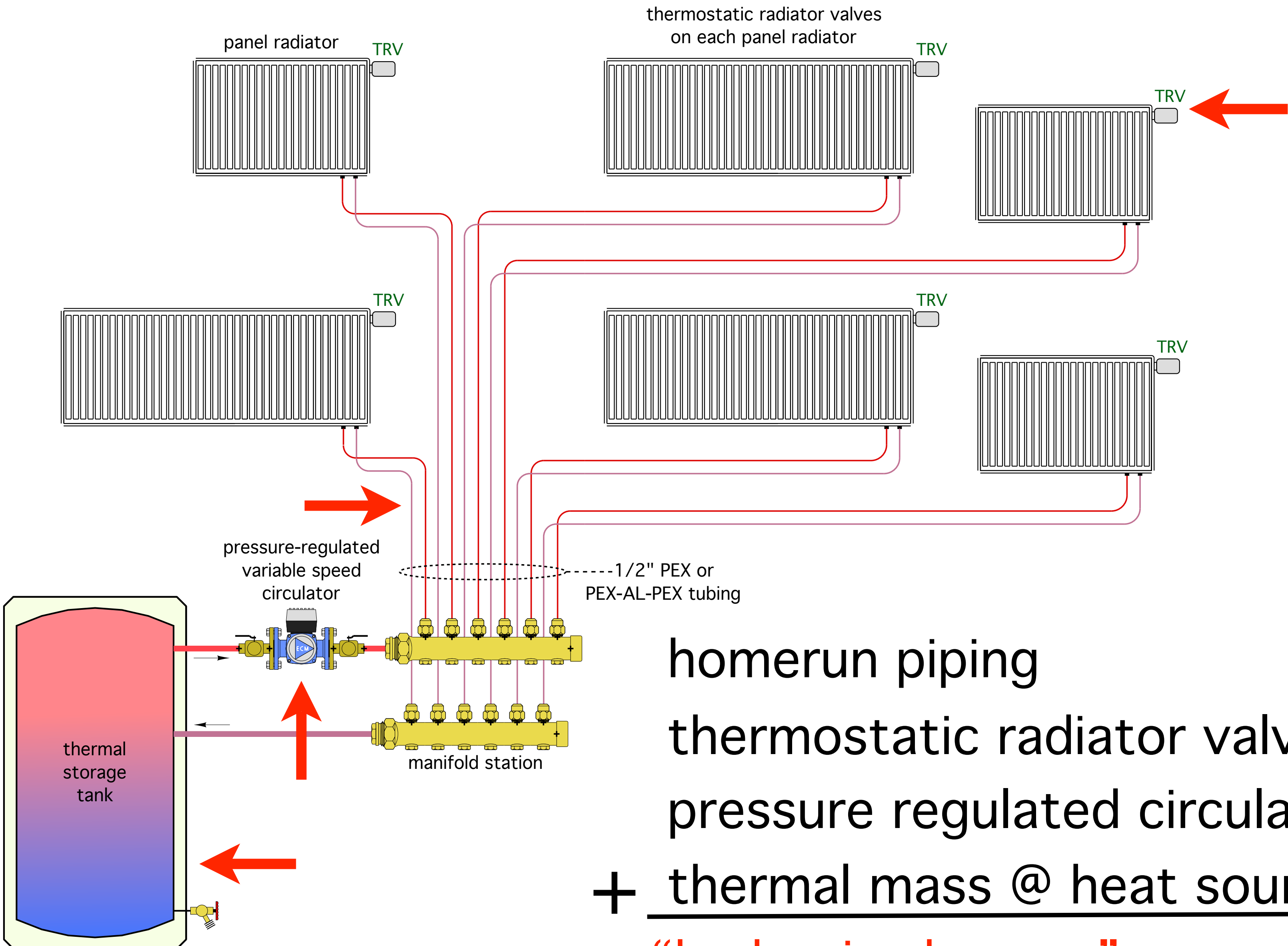
B&G ECO XL

Computer modeling has been used to predict electrical energy savings for an intelligently-controlled circulator with ECR motor operating in the proportional pressure mode.

Savings in electrical energy are 60 to 80 percent relative to a fixed speed circulator of equal peak performance in the same application.



Supplying a homerun distribution system...



homerun piping

thermostatic radiator valves

pressure regulated circulator

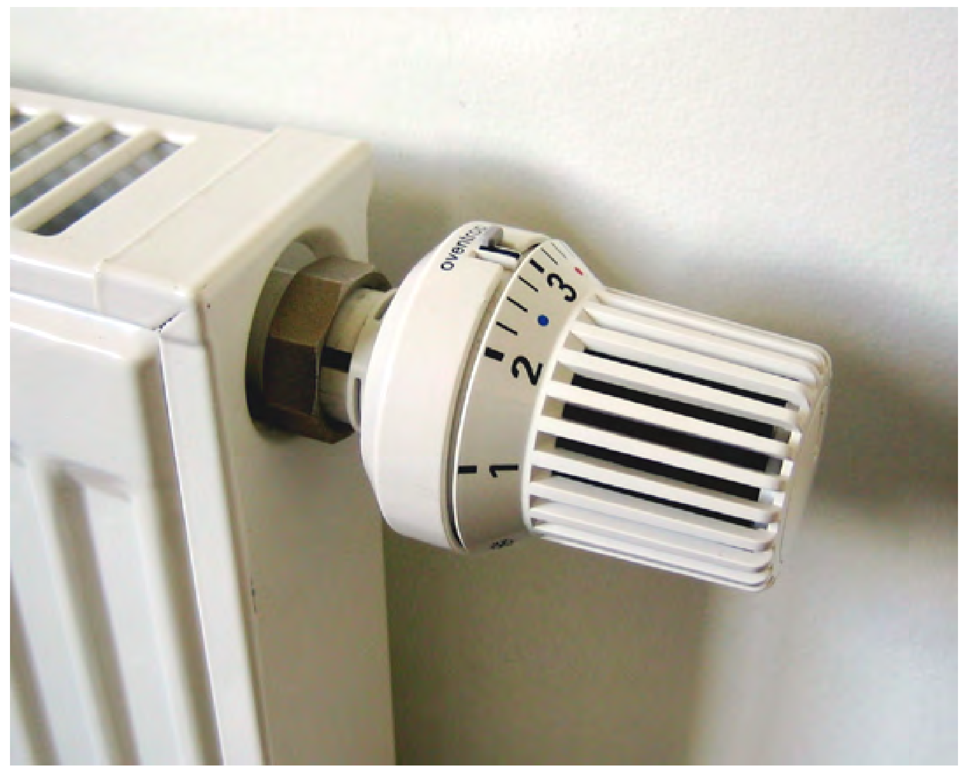
\+ thermal mass @ heat source

“hydronics heaven”

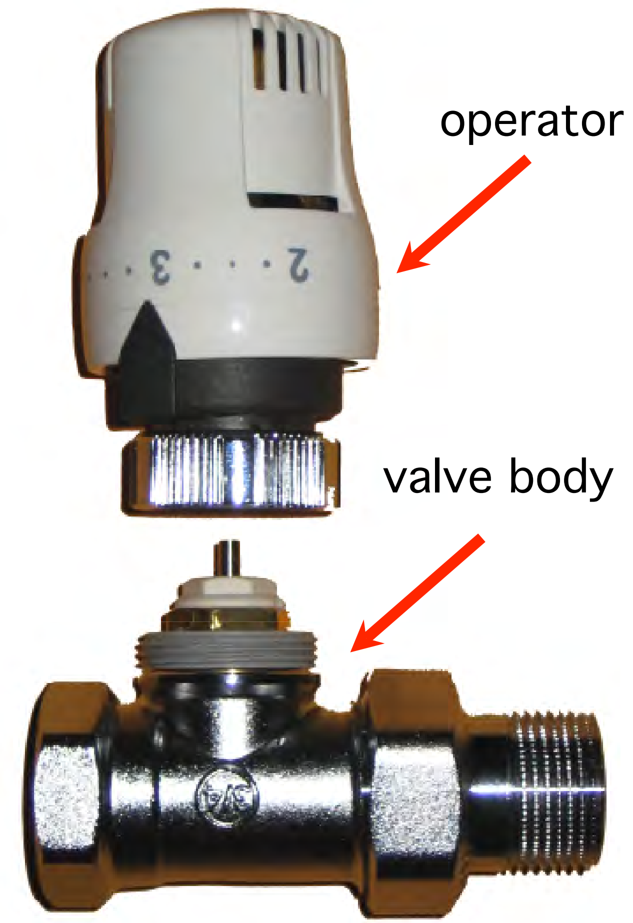
Homerun systems allow several methods of zoning.

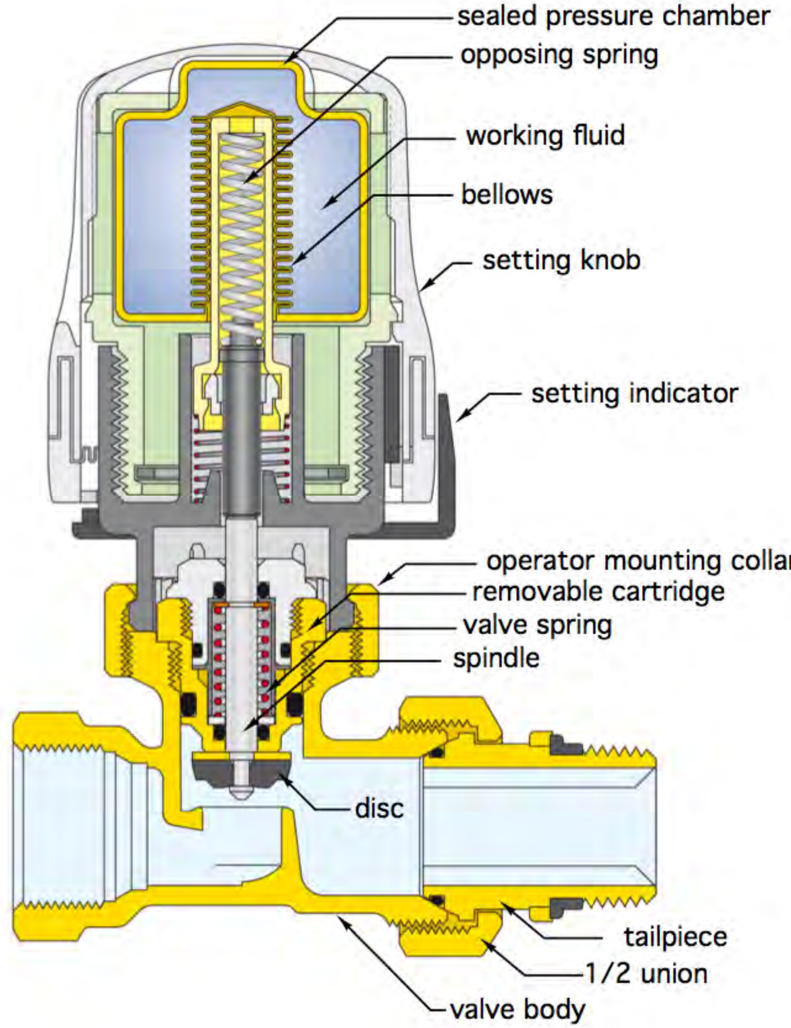
One approach is to install valved manifolds equipped with low voltage valve actuators on each circuit.

Another approach is to install a thermostatic radiator valve (TRV) on each heat emitter.



NON-ELECTRIC THERMOSTATIC RADIATOR VALVE:





thermostatic radiator valves are easy to use...

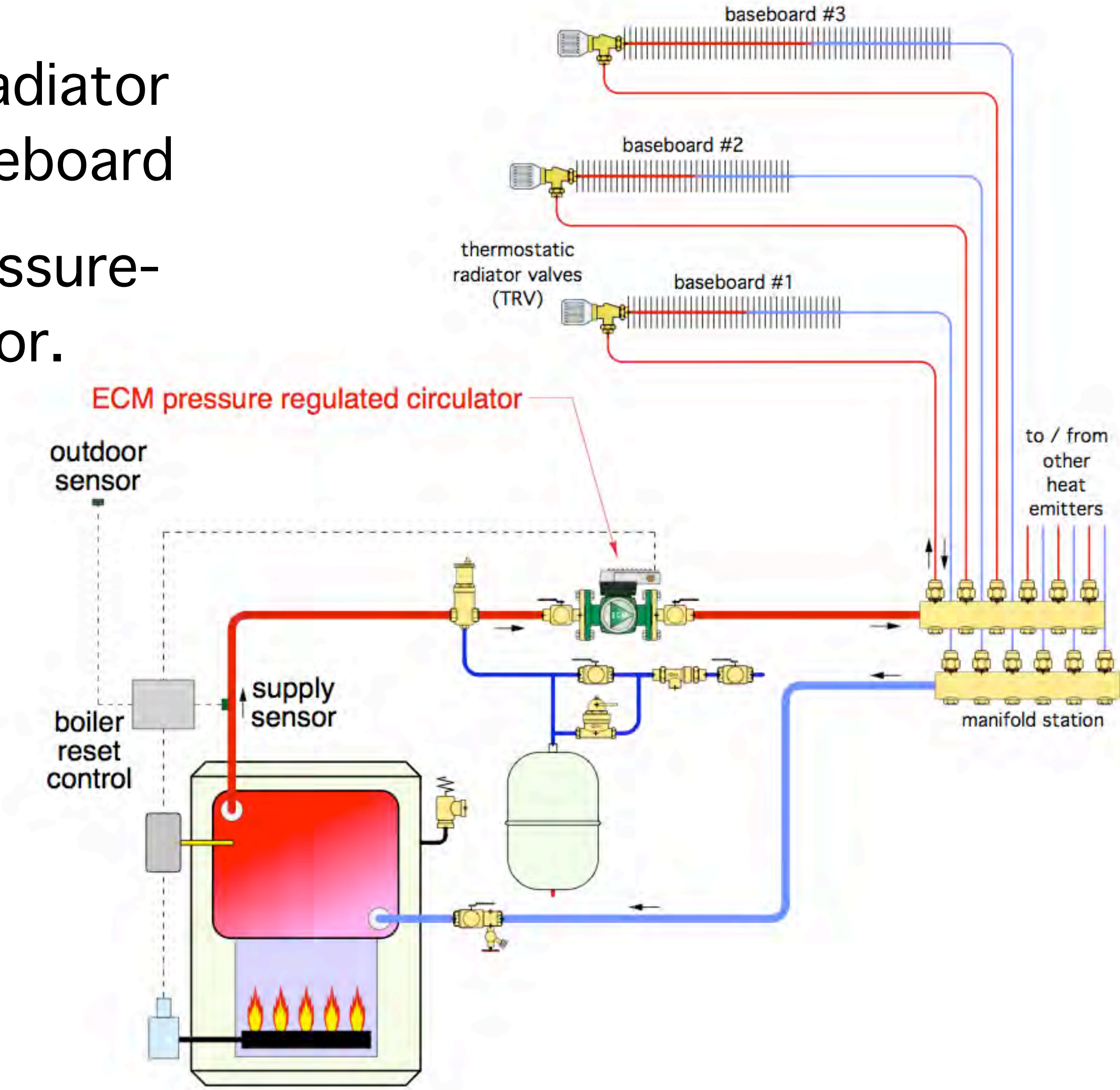
manual setback

dog reset control

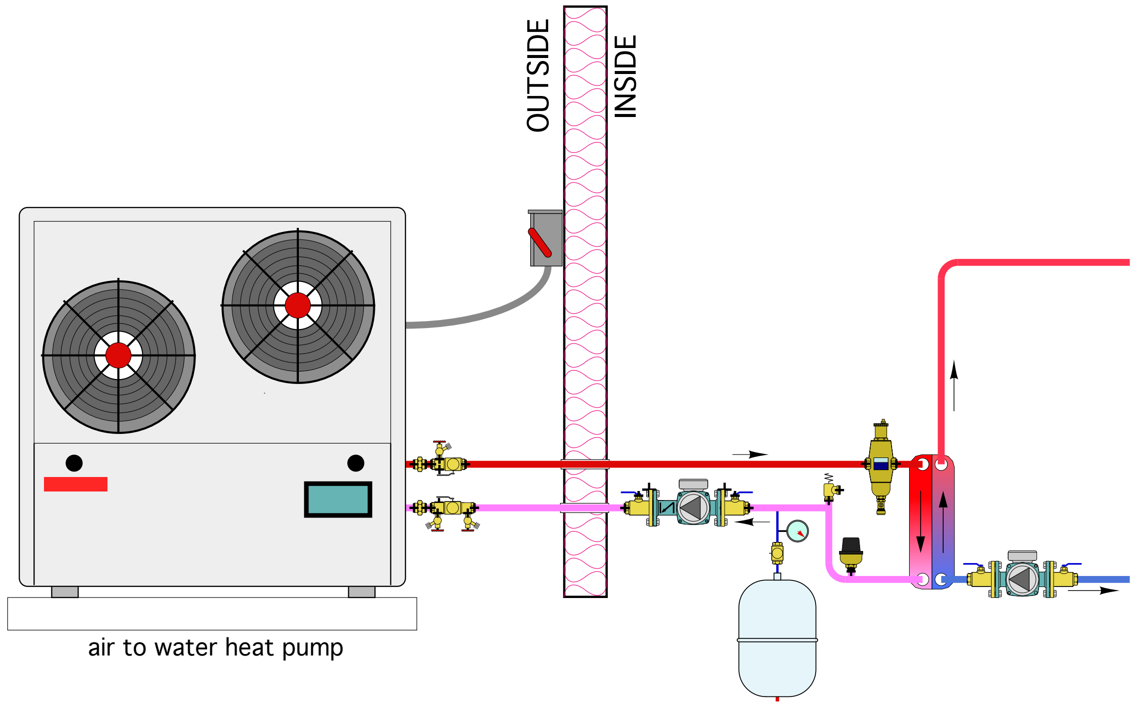
dogs are “thermally discriminating.”

The modern way to install fin-tube baseboard:

- Thermostatic radiator valve on each baseboard
- ECM-based pressure-regulated circulator.

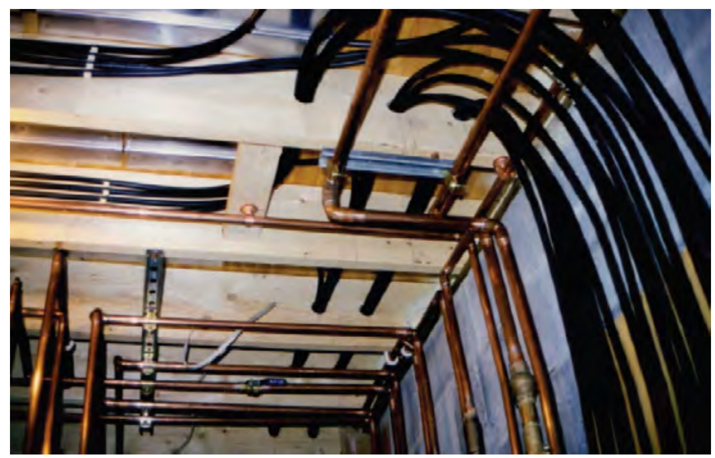


Air-to-Water Heat Pumps:



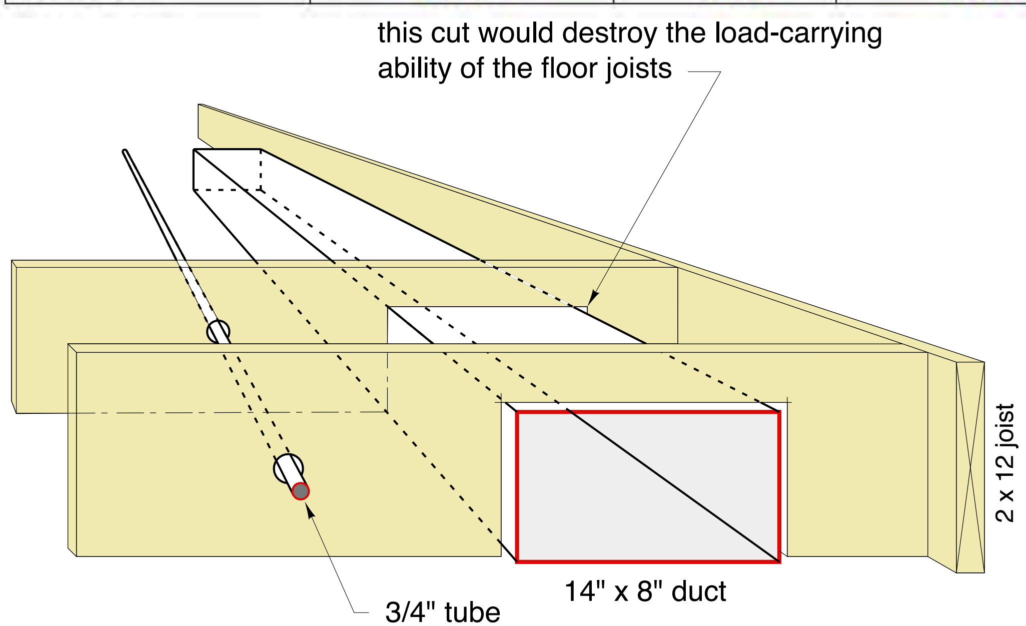
air to water heat pump

Why Water rather than air



Water is vastly superior to air for conveying heat

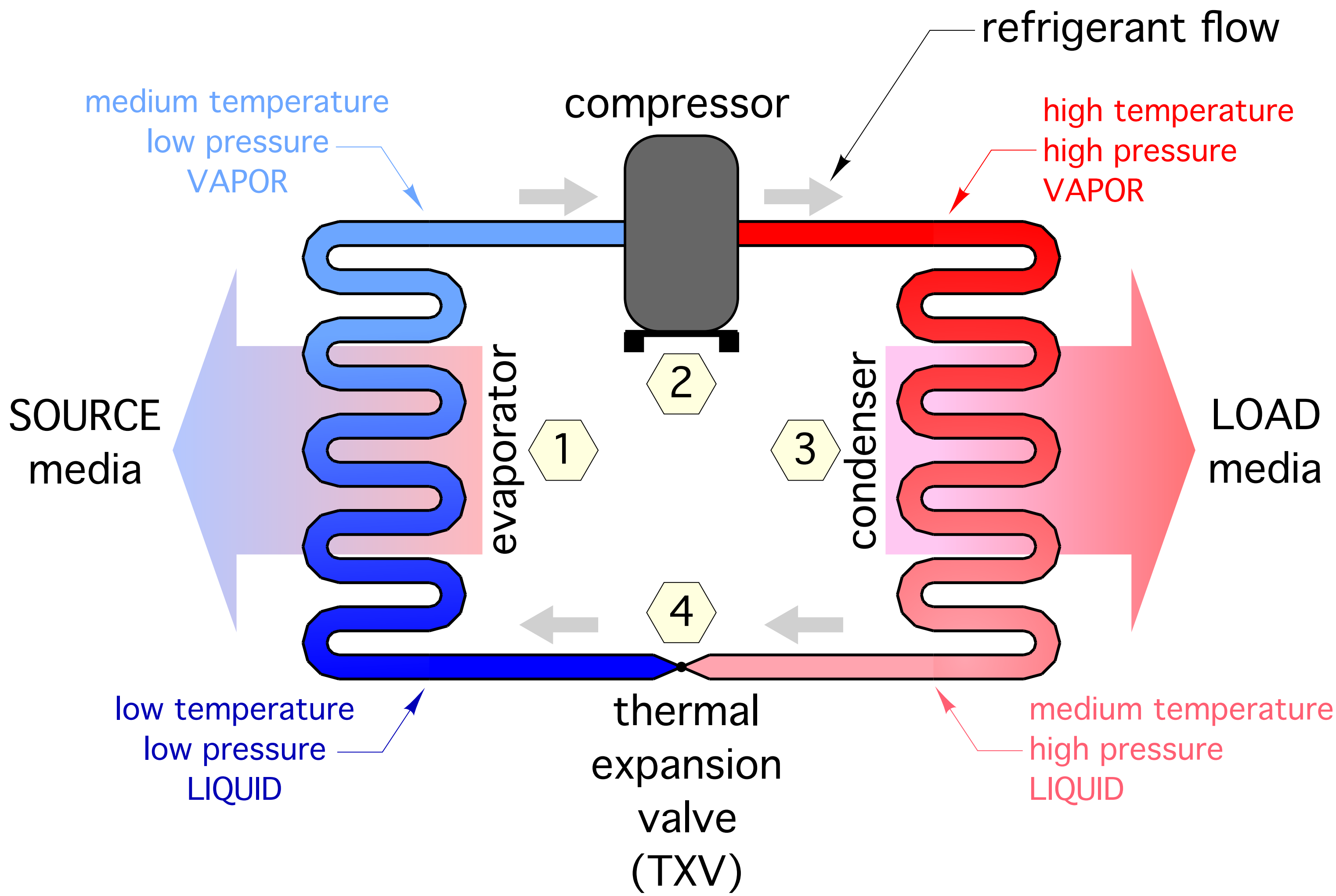
Material	Specific heat (Btu/lb/°F)	Density* (lb/ft^3)	Heat capacity (Btu/ft^3/°F)
Water	1.00	62.4	62.4
Concrete	0.21	140	29.4
Steel	0.12	489	58.7
Wood (fir)	0.65	27	17.6
Ice	0.49	57.5	28.2
Air	0.24	0.074	0.018
Gypsum	0.26	78	20.3
Sand	0.1	94.6	9.5
Alcohol	0.68	49.3	33.5



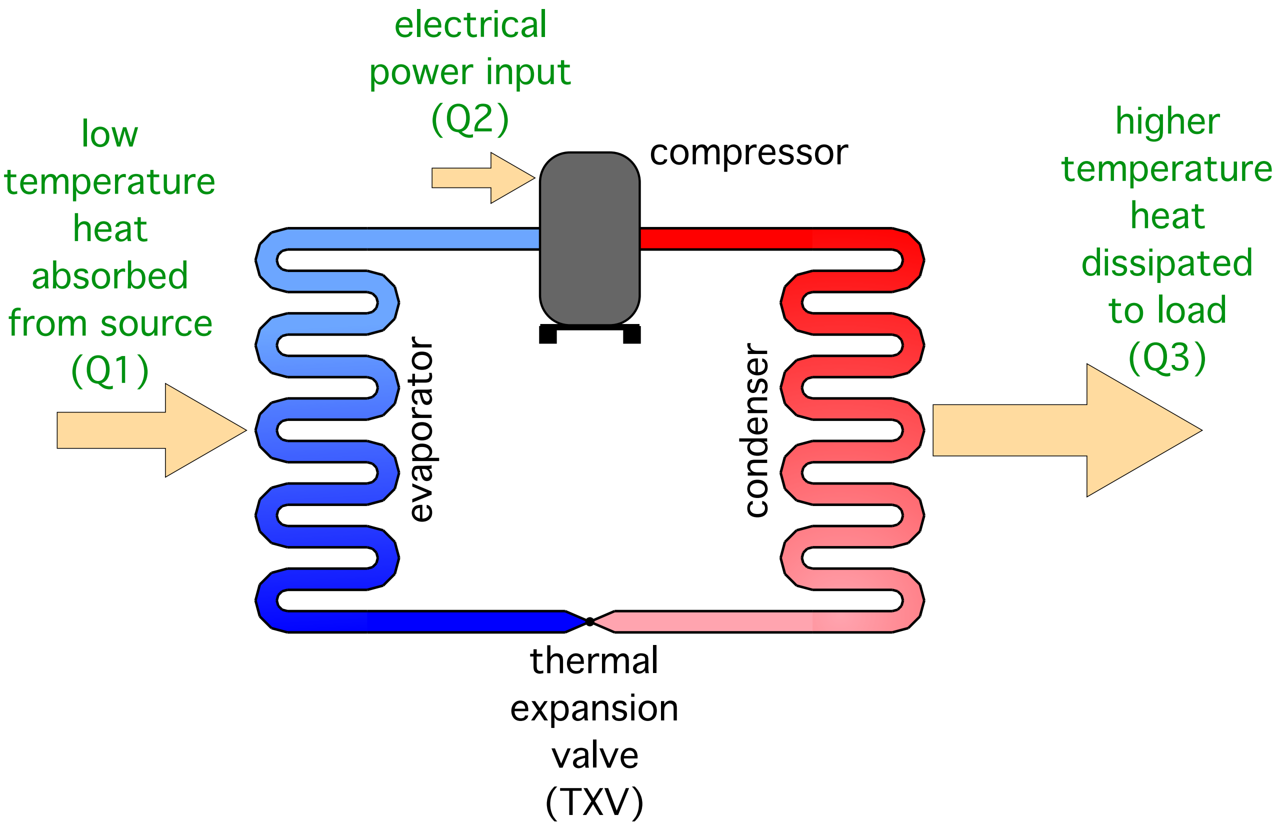
$$\frac{62.4}{0.018} = 3467 \approx 3500$$

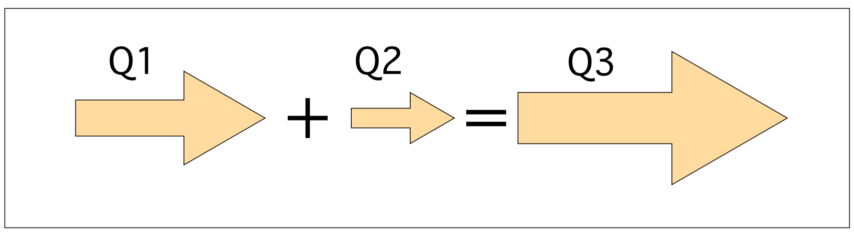
A given volume of water can absorb almost 3500 times as much heat as the same volume of air, when both undergo the same temperature change

Basic heat pump operation



Basic heat pump operation

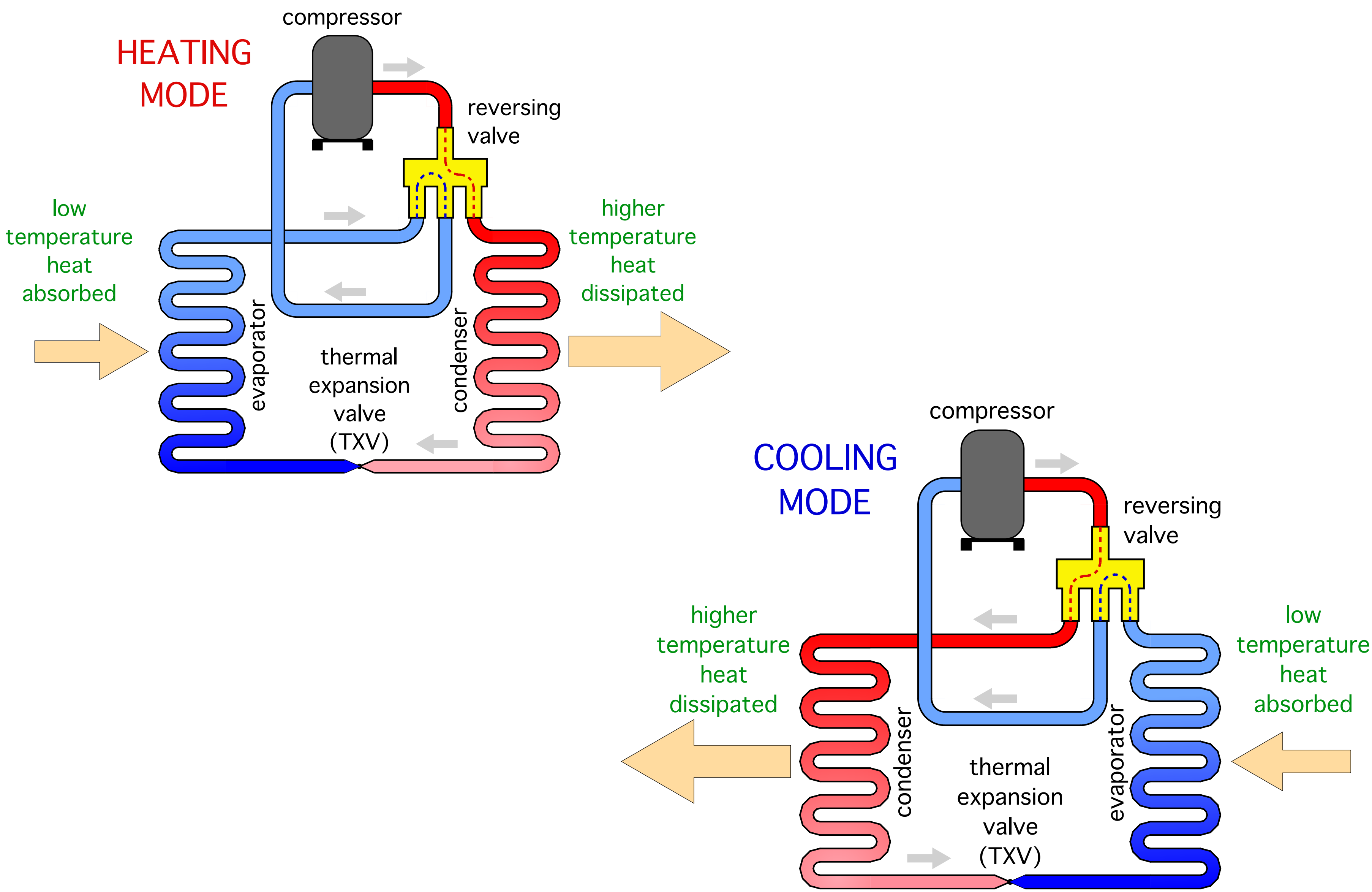




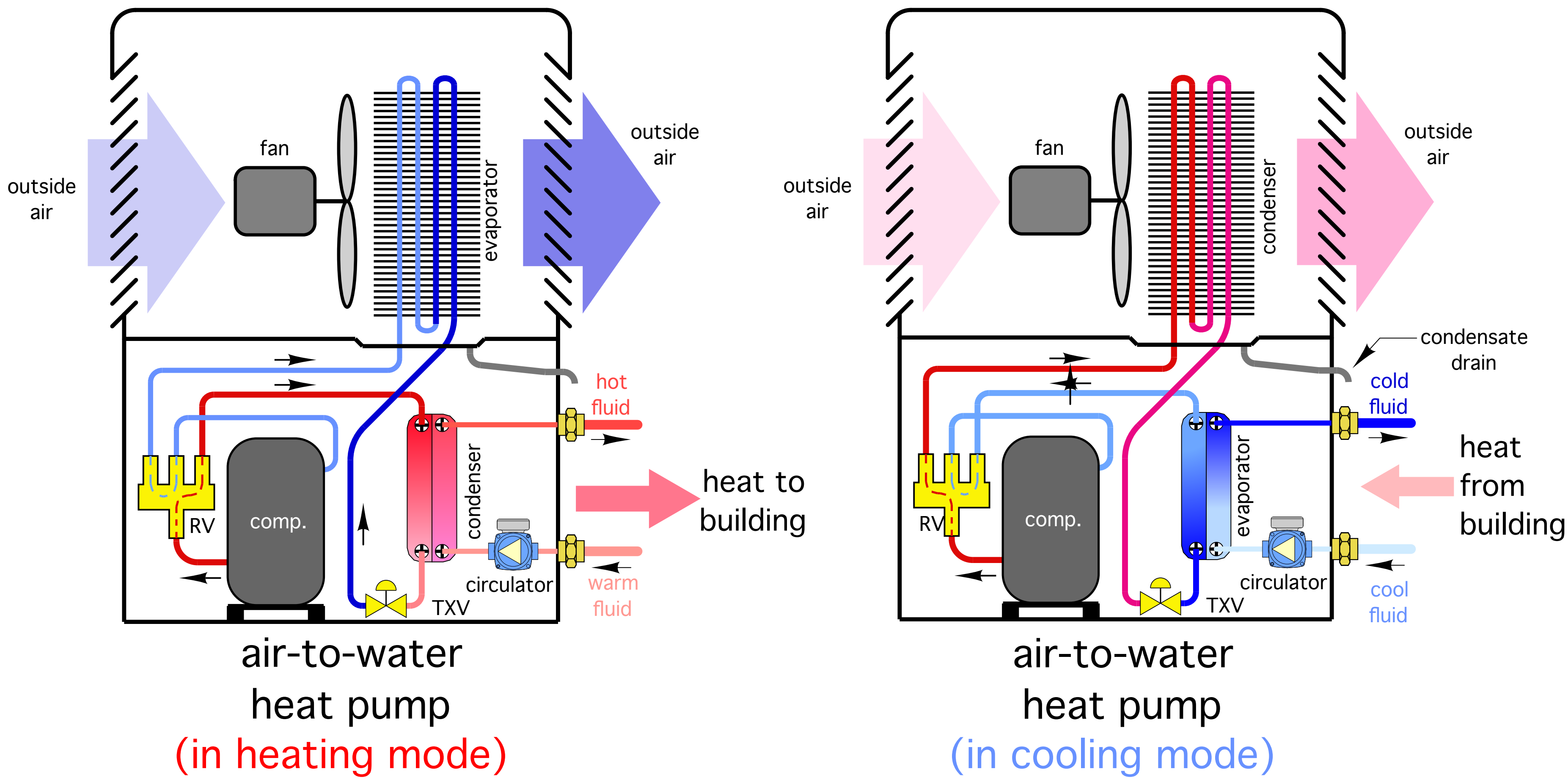
$$COP = \frac{Q3}{Q2}$$

$$\text{COP} = \frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413}$$

Basic heat pump operation (reversible heat pumps)

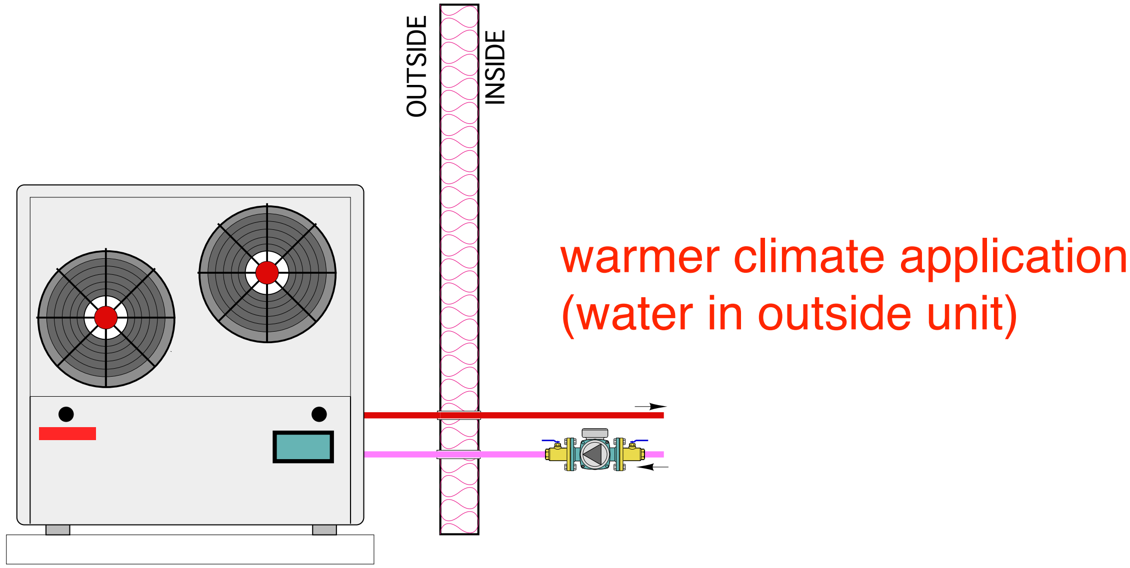


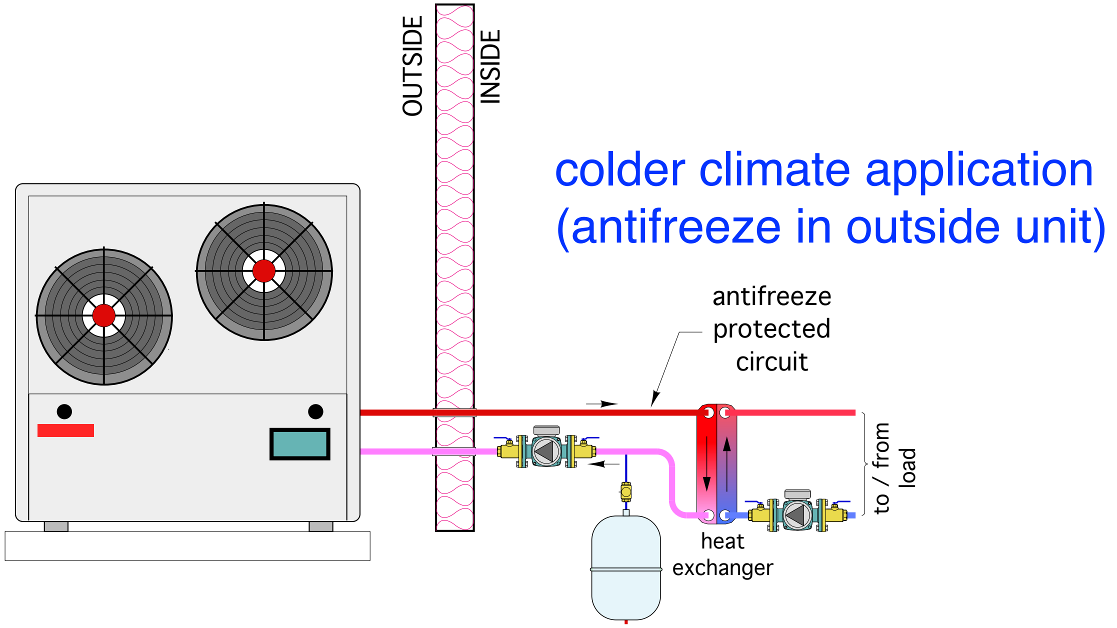
Refrigeration cycle in AWHP



Self-contained air-to-water heat pumps

image courtesy of SpacePak





- Heating + cooling + DHW
- Pre-charged refrigeration system
- 2-stage operation for better load matching
- No interior space required
- No interior noise

One comparison with Geothermal w/w heat pump:

Example house: 36,000 BTU/hr design load at 70ºF inside & 0 ºF outside

Location: Syracuse, NY (6720 heating degree days)

Total estimated heating energy required: 49.7 MMBTU / season

Average cost of electricity: $0.13/kwhr

Distribution system: radiant panels with design load supply temperature = 110ºF

AIR-TO-WATER HEAT PUMP OPTION

Based on simulation software, a nominal 4.5 ton split system air-to-water heat pump supplying this load has a

seasonal COP = 2.8.

Estimated installed cost = $10,600 (not including distribution system)

GEOTHERMAL WATER-TO-WATER HEAT PUMP OPTION:

Based on simulation using simulation software, a nominal 3 ton water to water heat pump supplying this load from a vertical earth loop has a **seasonal COP = 3.28**.
Estimated installed cost = **$11,800 (earth loop)** + $8750 (balance of system) = $20,550 (not including distribution system)
Deduct for 30% federal tax credit: ($ -6165)

Net installed cost: $14,385 (not including distribution system)

Annual space heating cost:

AIR-TO-WATER HEAT PUMP (COP_{ave}= 2.8) = $676 / yr

GEOTHERMAL HEAT PUMP (COP_{ave} = 3.28) = $578 / yr

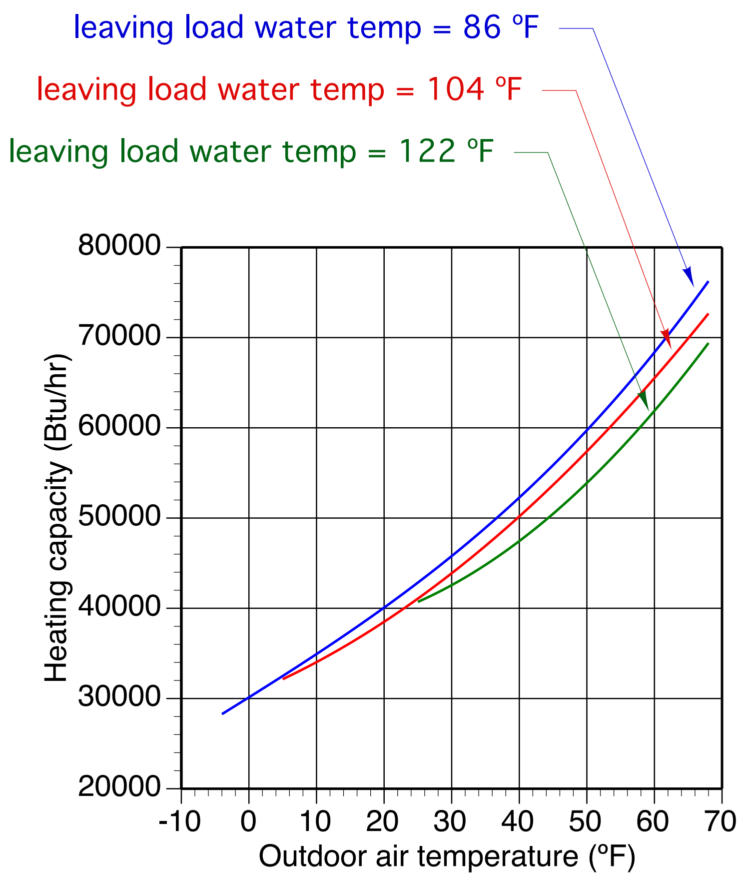
Difference in annual heating cost: $98 / year

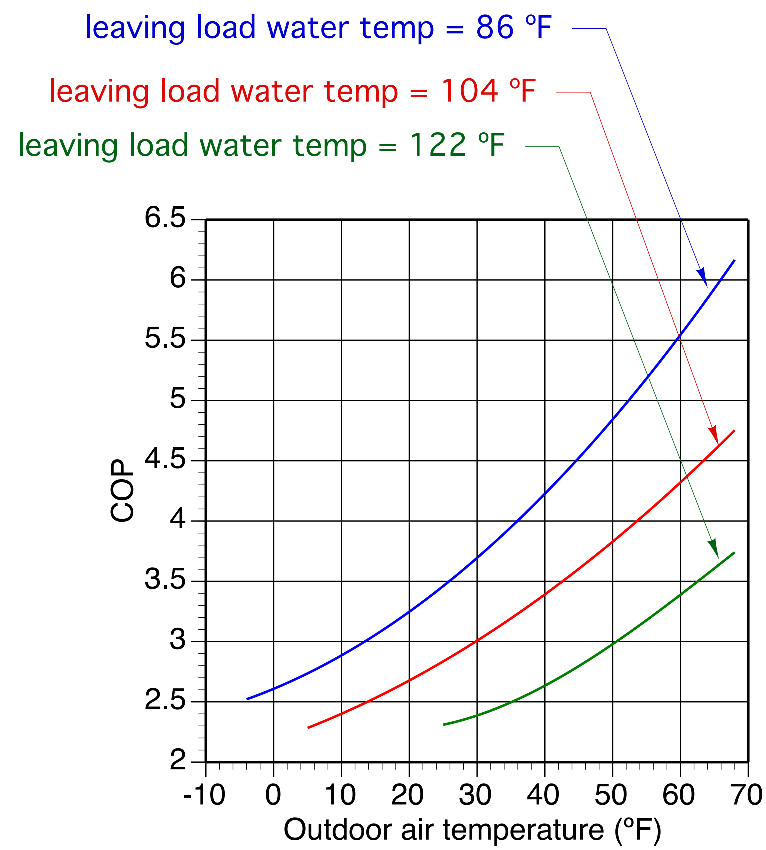
Difference in net installed cost: $3,785

Simple payback on higher cost of geothermal HP: 3785 / 98 ≈ 38 years

Heading performance:

$$COP = \frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413}$$





Heating capacity

Increases with:

a. warmer outdoor temperature

b. lower load water temperature

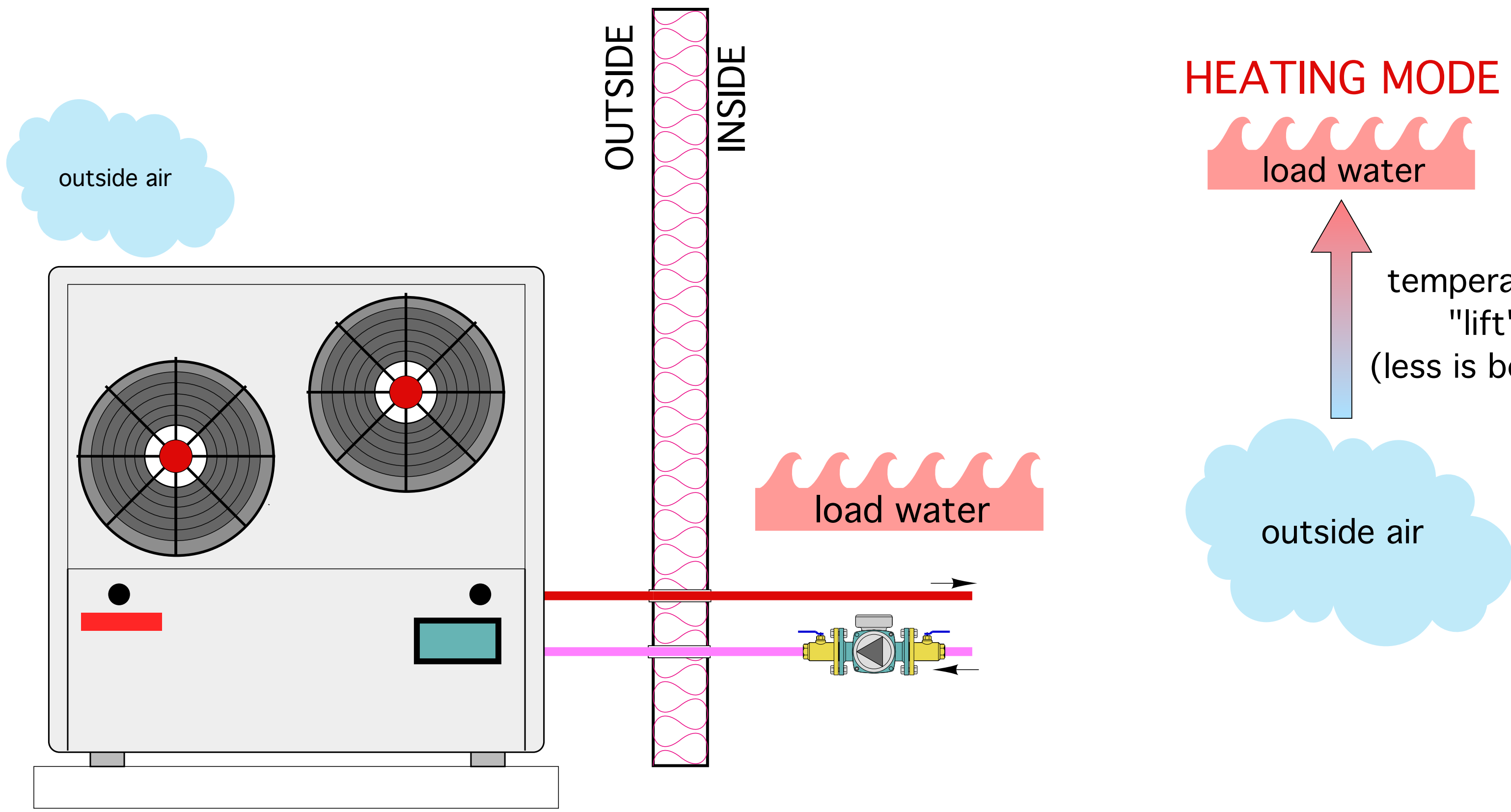
COP

Increases with:

a. warmer outdoor temperature

b. lower load water temperature

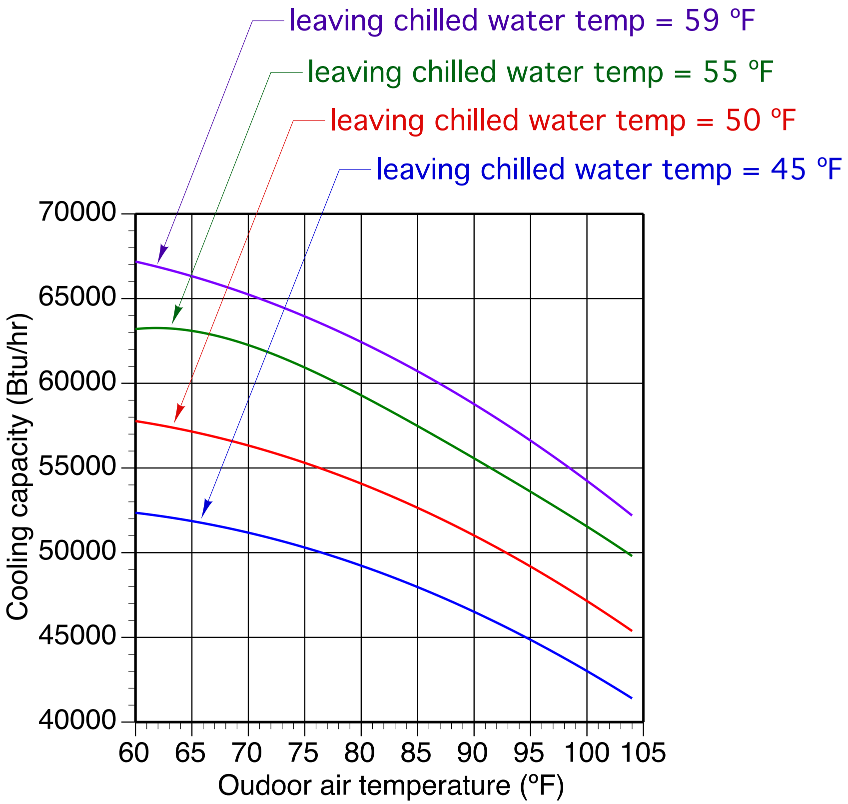
Heating performance:

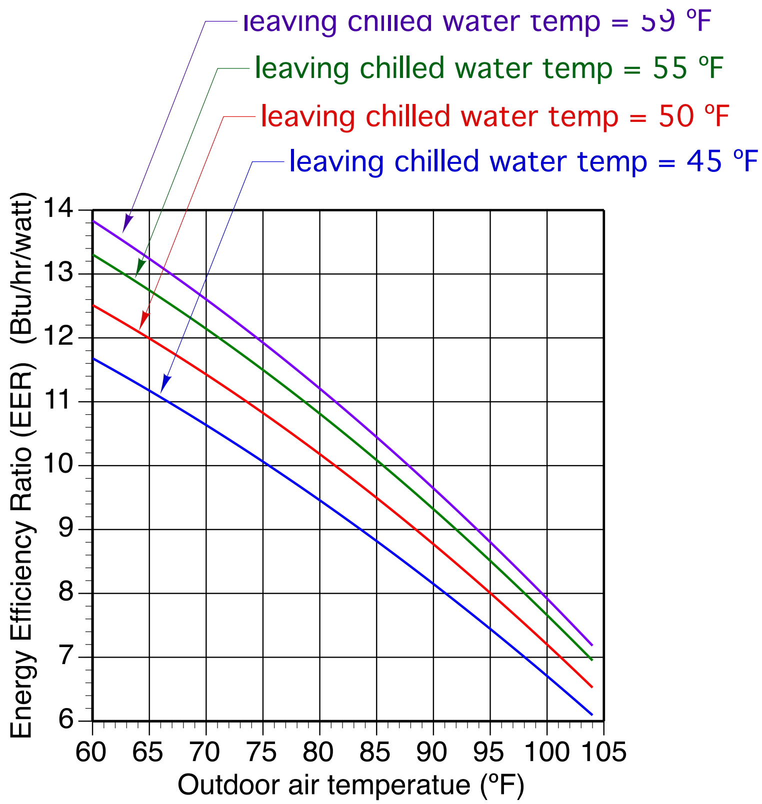


Anything that *reduces* the "temperature lift" *increases* both the heating capacity and COP of the heat pump.

Low temperature distribution systems are critical to good performance.

Cooling performance:

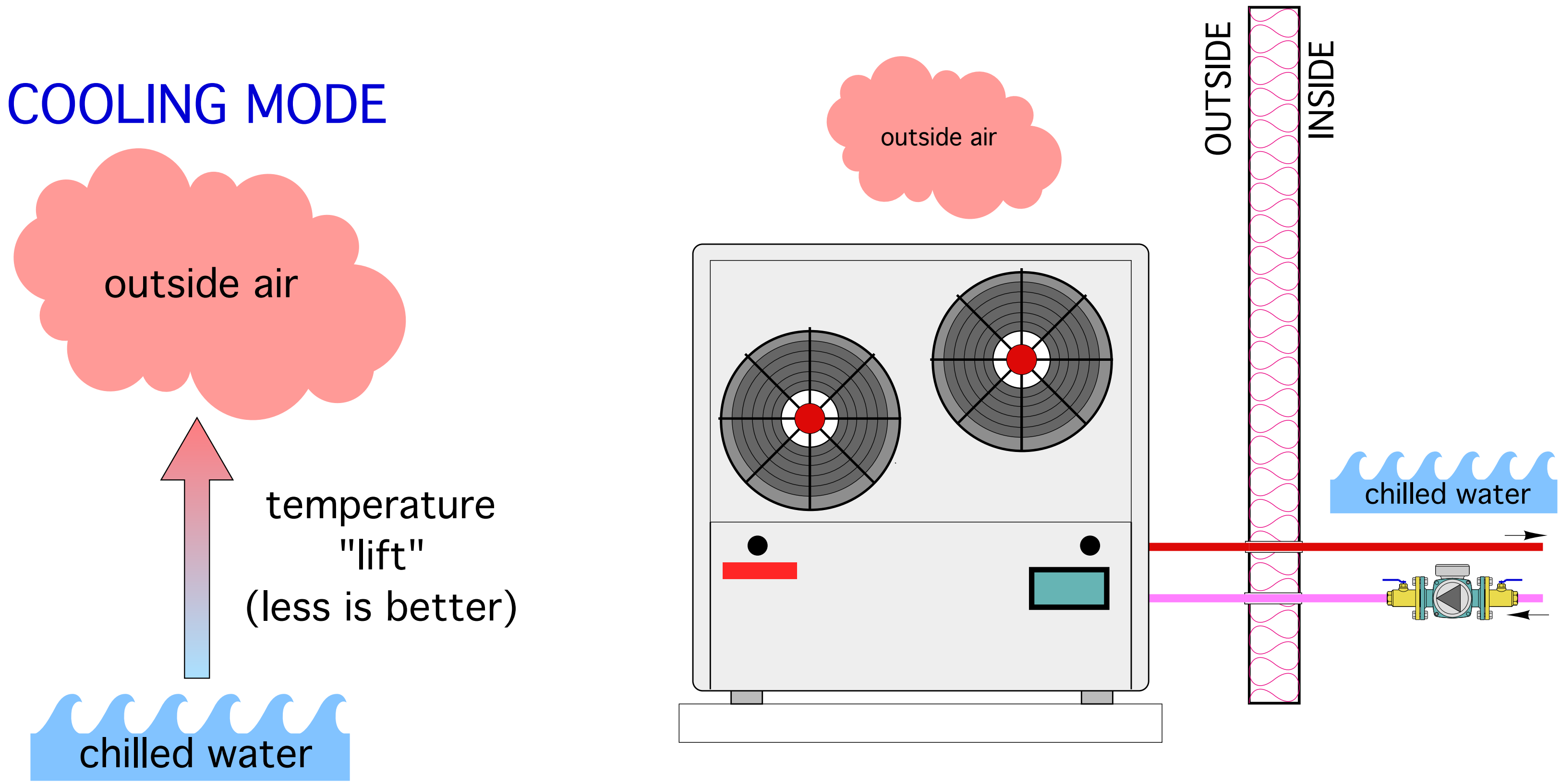




Cooling capacity
Increases with:
a. lower outdoor temperature
b. Higher chilled water temperature

EER
Increases with:
a. lower outdoor temperature
b. higher chilled water temperature

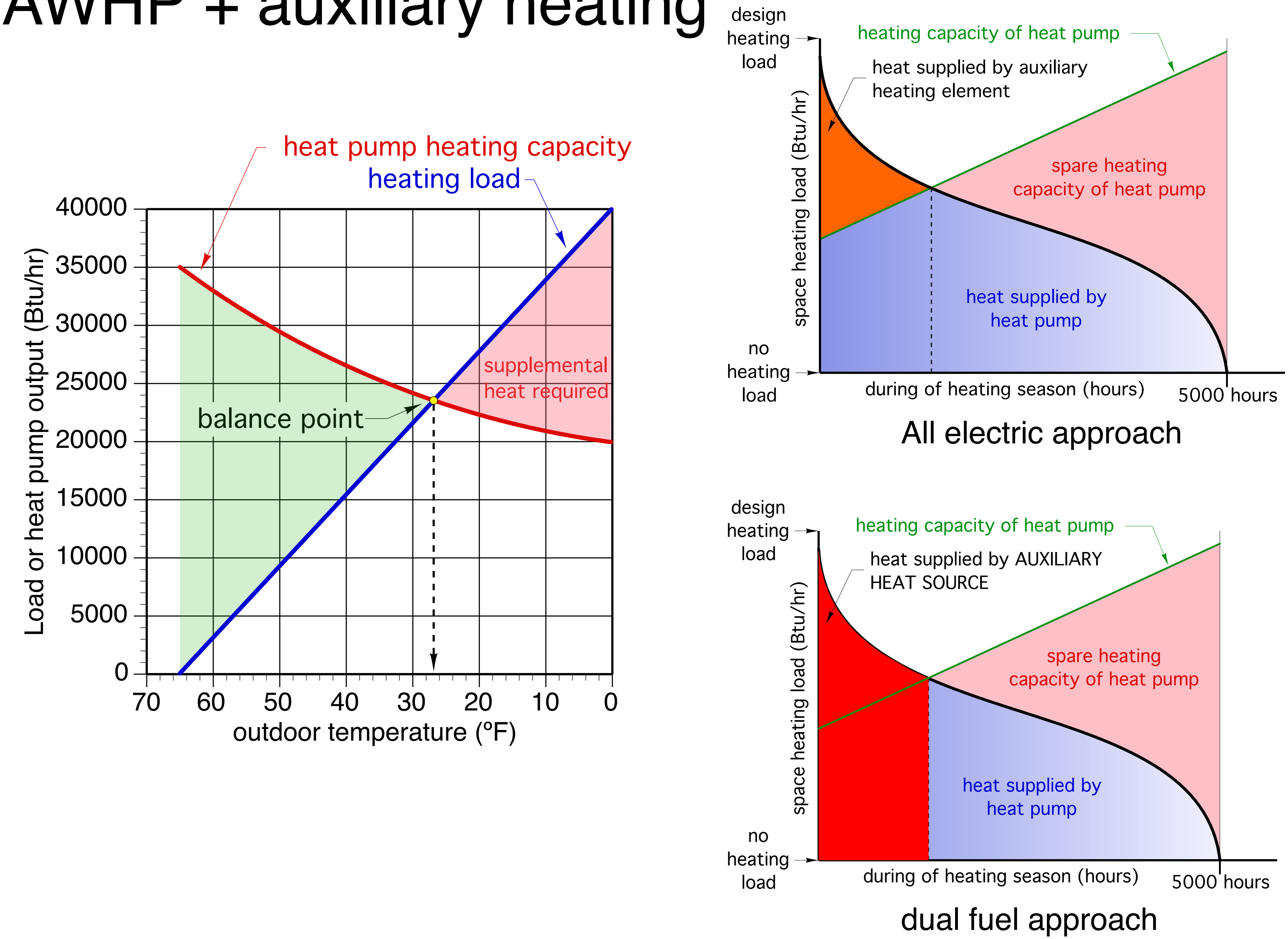
Cooling performance:



Anything that decreases the temperature lift' increases both the cooling capacity and EER of the heat pump.

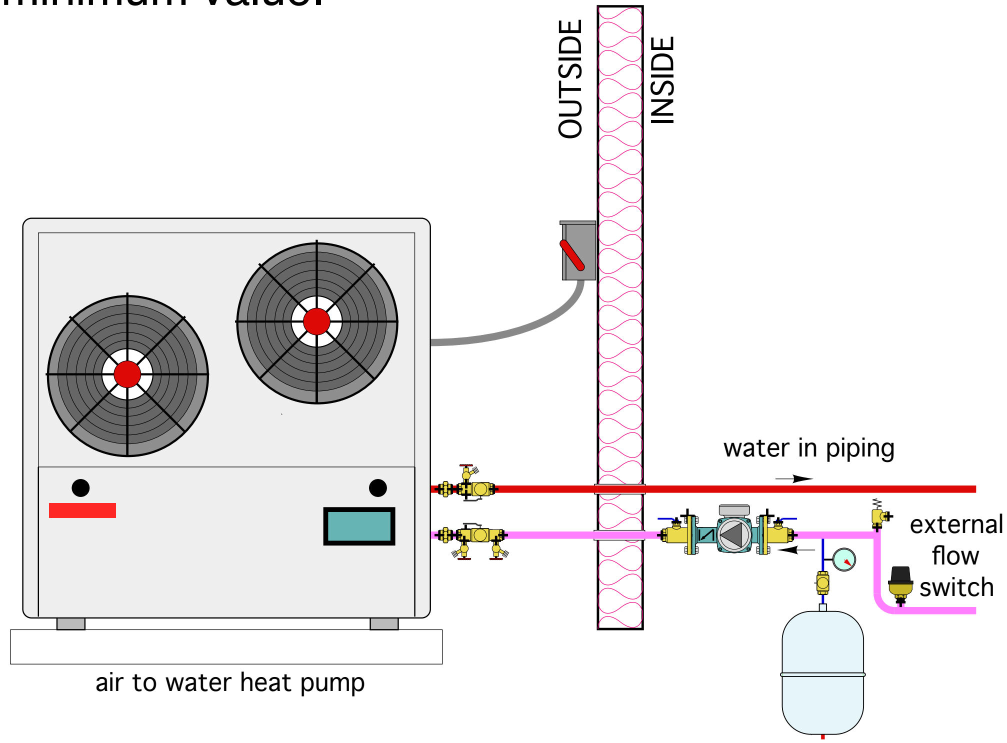
Warmer chilled water temperatures improve performance.

AWHP + auxiliary heating



Flow switches protect the heat pump

An internal or external flow switch turns off the refrigeration cycle if water flow through the heat pump stops, or falls below a minimum value.



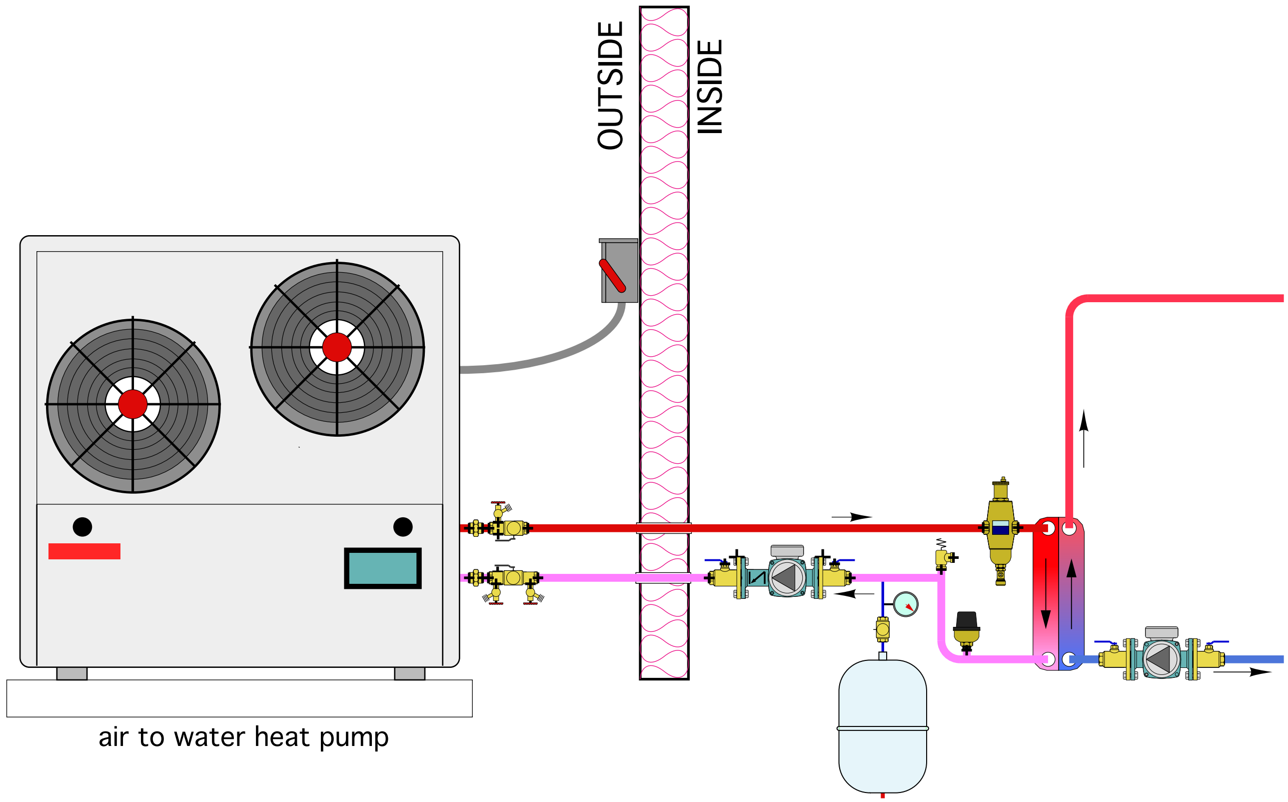
internal flow switch

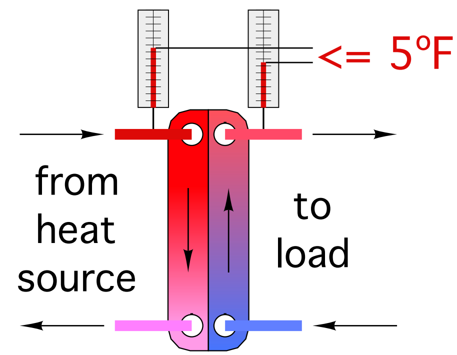
external flow switch

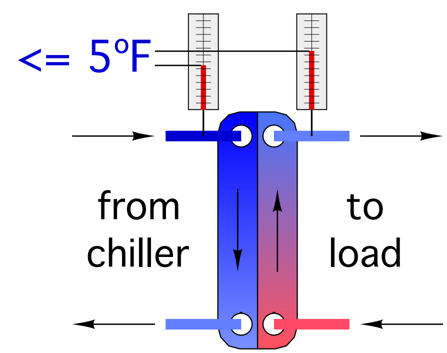
In cooling mode this prevents possible freezing of a water-heated evaporator.

In heating mode this prevents excessive head pressure in compressor (because the heat pump is unable to dissipate the heat to the remainder of the system).

Heat exchangers between heat pump and distribution system

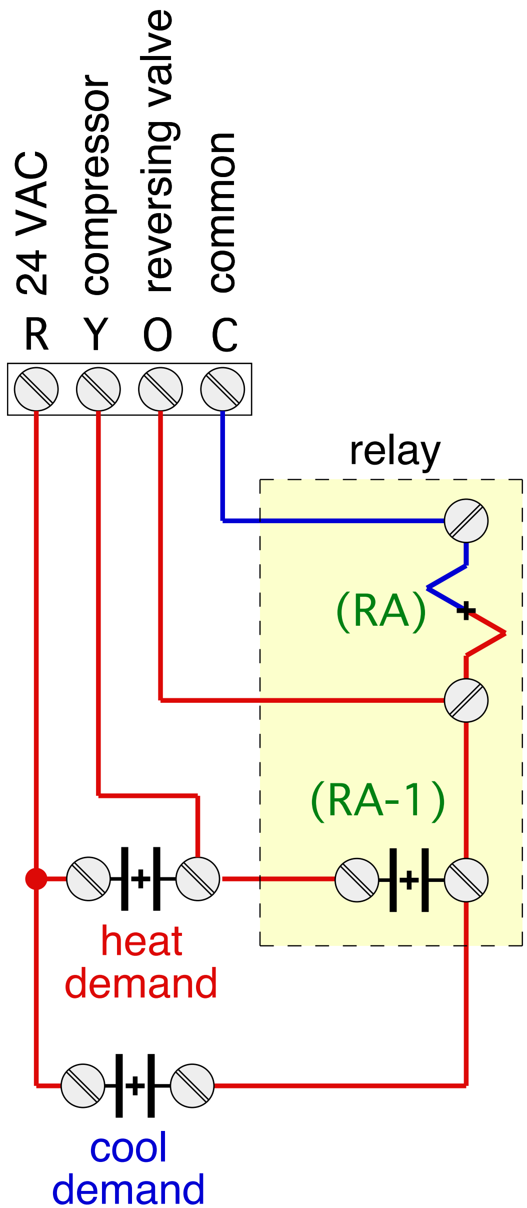






IF a heat exchanger is required between heat pump and storage (due to requirement to keep heat pump part of a closed loop), that heat exchanger should be sized for a maximum approach temperature difference of 5 ºF.

Low voltage interfacing with AWHP

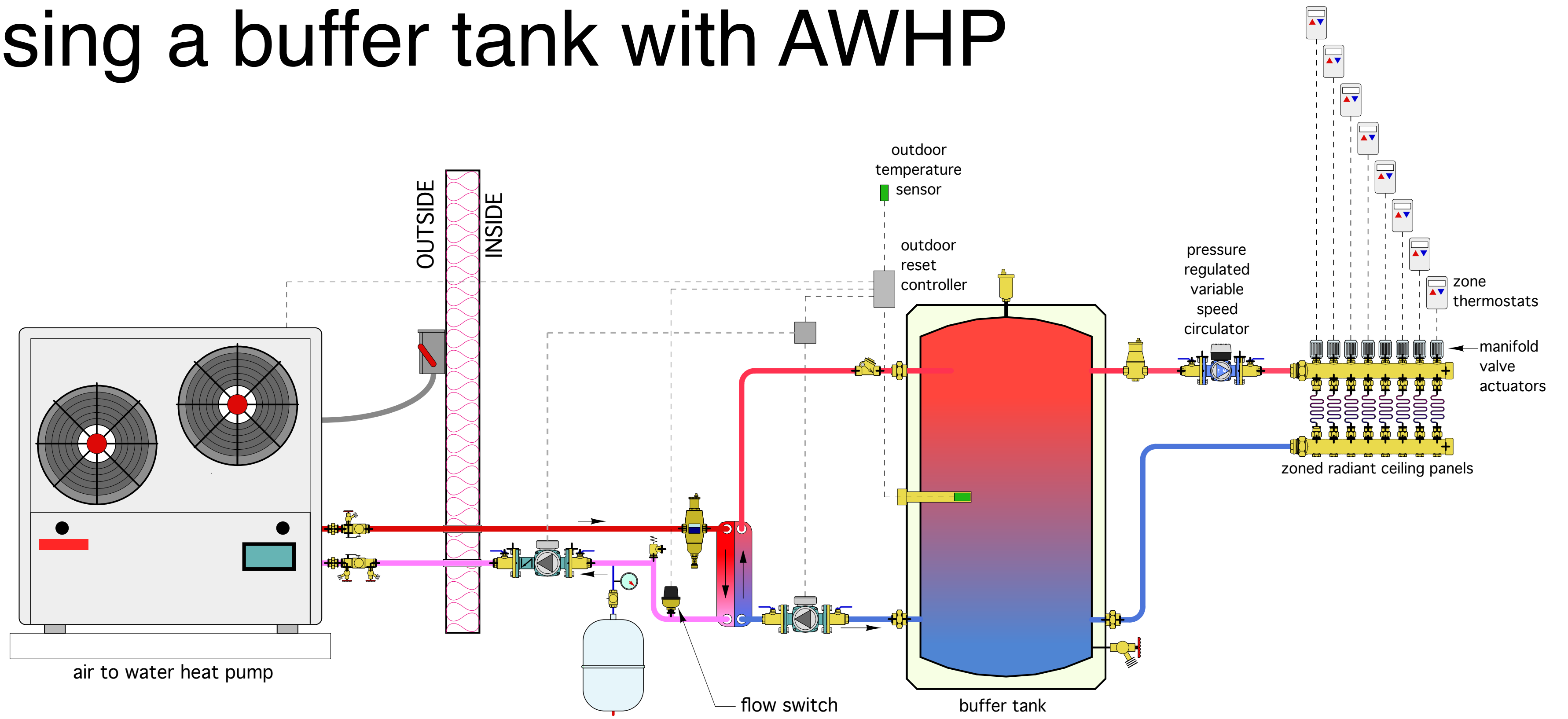


In heating mode: 24 VAC from R to Y turns on compressor (and internal circulator if present).

In cooling mode: Cooling demand contact closes to provide 24 VAC from R to relay coil, then to C, turns on relay (RA). Contact RA-1closes to send 24VAC to Y to turn on compressor (and internal circulator if present). 24 VAC is also passed to O to energize reversing valve (for cooling mode operation).

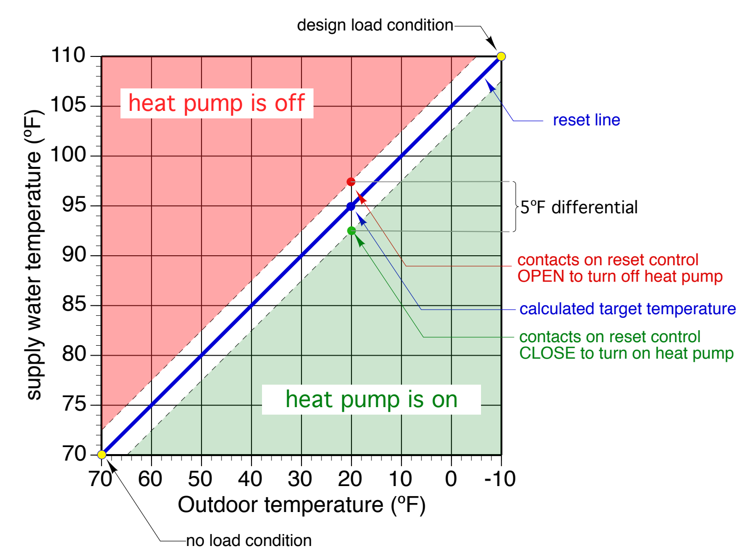
Some thermostats provide this logic without external relays.

Using a buffer tank with AWHP



Buffer tanks prevent the heat pump from short cycling when connected to a highly zoned distribution system.

In this system, the average temperature of the buffer tank is controlled by outdoor reset. This helps increases the COP of the the AWHP during partial load conditions.



Using a buffer tank with AWHP

$$V_{btank} = \frac{t\left(Q_{HP} - Q_L\right)}{500\left(\Delta T\right)}$$

Where:

V_{btank} = required volume of buffer tank (gallons)

t = desired on-time for heat source (minutes)

Q_{HP} = heating capacity of heat pump (Btu/hr)

Q_L = any heating load served by buffer tank while charging (Btu/hr)

ΔT = allowed temperature rise of tank during heat pump on-time (°F)

Determine the size of a buffer tank that will absorb 48,000 Btu/hr from the heat pump while increasing i temperature from 90 °F to 110 °F, during a heat pump on-cycle of 10 minutes. There is no heating load on the tank during this charging.

$$V_{btank} = \frac{t\left(Q_{HP} - Q_L\right)}{500\left(\Delta T\right)} = \frac{10\left(48000 - 0\right)}{500\left(20\right)} = 48\,gallons$$

If the allowed temperature rise was 10 °F, rather than 20°F, the required tank volume would double to 96 gallons. If the desired on-time was only 5 minutes rather than 10 minutes, the volume would be cut in half. Anything that increases the desired on-time, or decreases the allow temperature rise during this on-time, will increase the required tank volume, and vice versa.

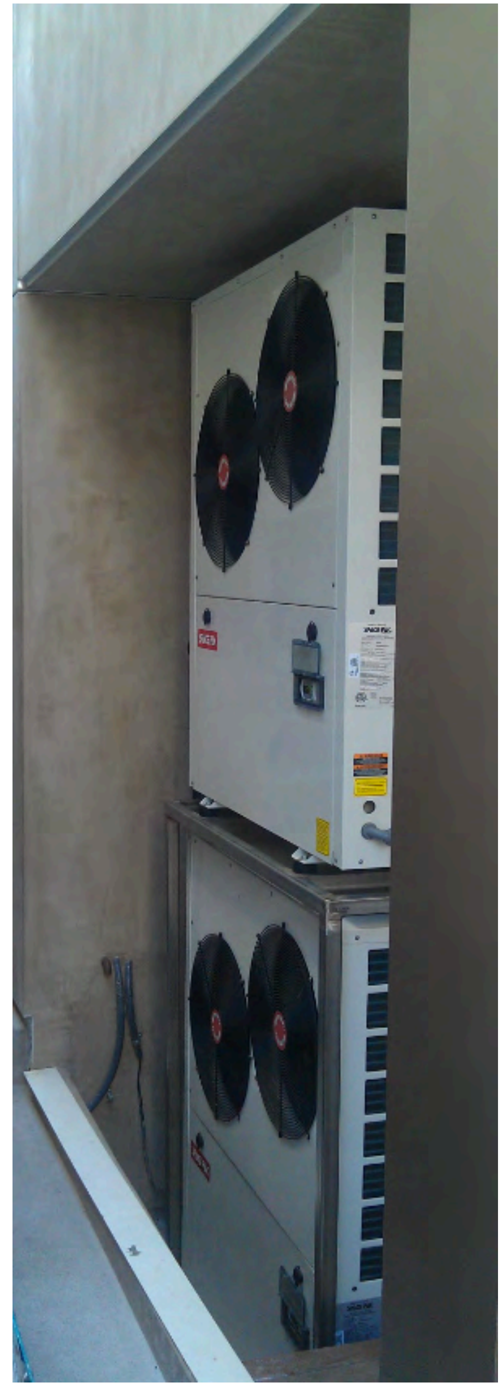
Multiple (staged) AWHP

image courtesy of Mestek

image courtesy of ReVision Energy

- *Provide adequate space for air flow*
- *Respect prevailing winds*
- *In snowy climates, elevated above snow line*

Multiple (staged) AWHP



vertical rack mounting in alcove

- *Provide adequate space for air flow*
- *Minimize air flow interaction b/w adjacent HPs*

Multiple (staged) AWHP

Staged AWHP heat pumps for 20,000 square foot house.

image courtesy of Foley Mechanical

Heat emitters for AWHP systems

• They should operate at **low supply water temperatures** to enhance the thermal efficiency of the heat pump.

Max suggested supply water temperature @ design load = 120 ºF

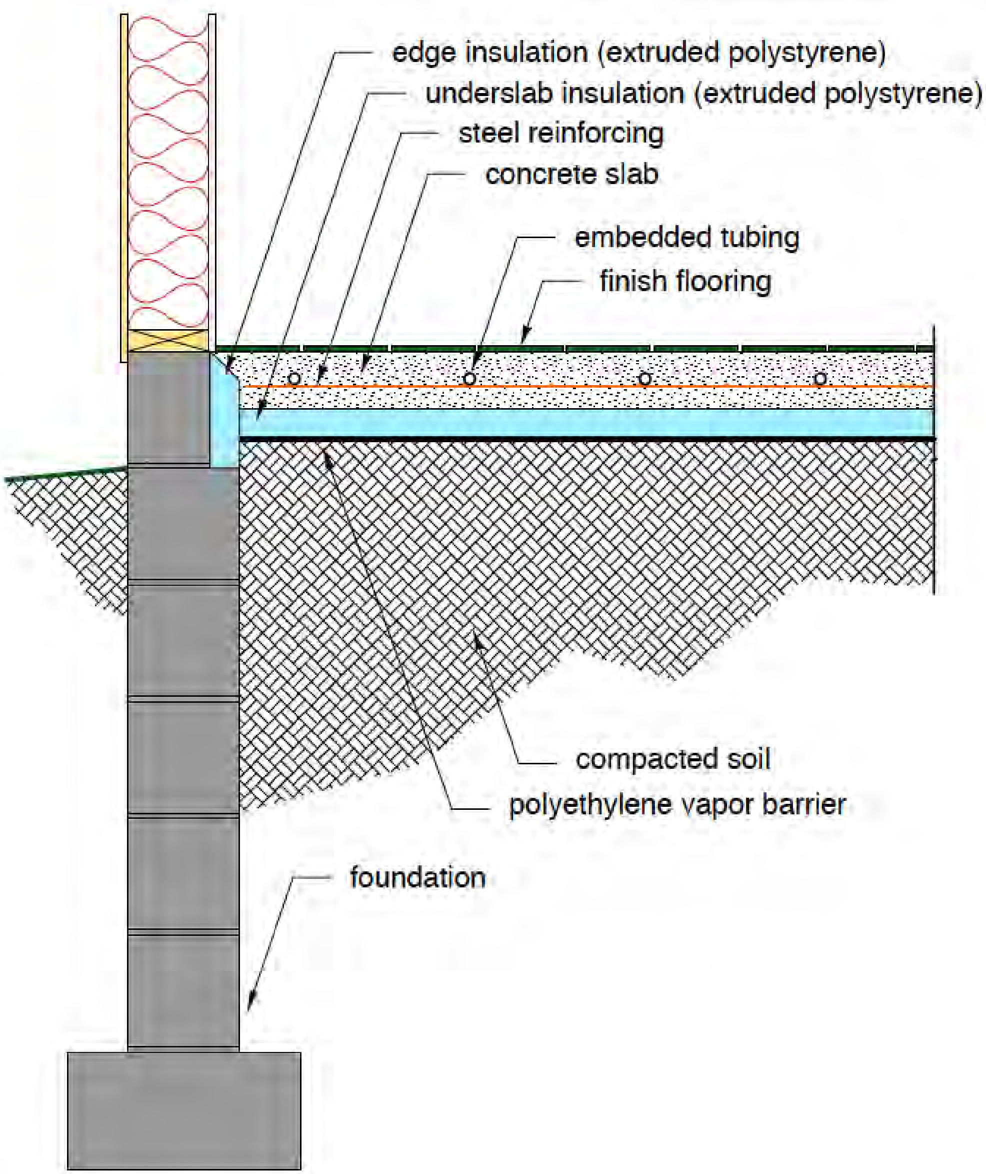
• They should permit simple **room-by-room zone control**

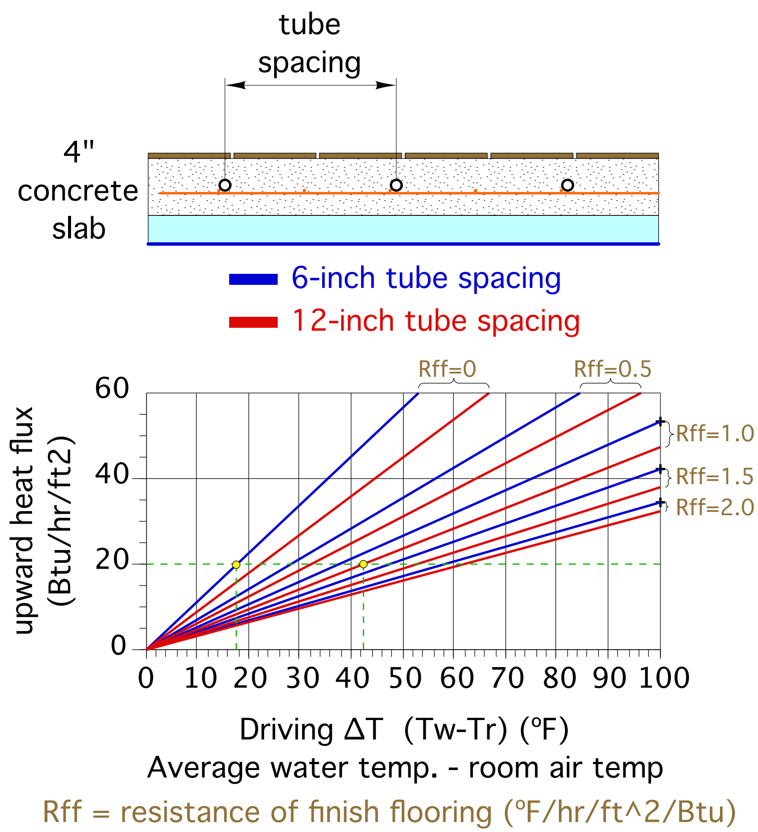
• They should not be subject to future changes that could reduce performance
(no carpet / rugs added over heated floors)

• They should not create noticeable drafts or other discomfort
(avoid operating conventional fan coils or air handlers at supply air temperatures lower than 100 ºF)

What's one type of hydronic heat emitter that works well at low water temperatures?

Slab-on-grade floor heating





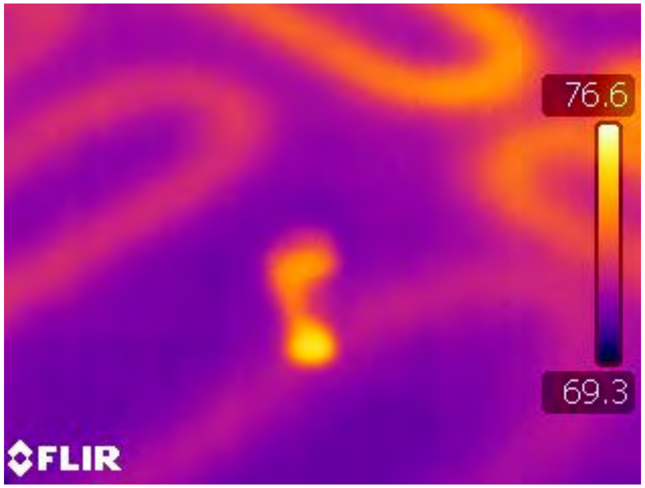
Is radiant floor heating always the answer?

“Barefoot friendly” floors...

Is radiant floor heating always the answer?

Consider a 2,000 square foot well insulated home with a design heat loss of 18,000 Btu/hr. Assume that 90 percent of the floor area in this house is heated (1800 square feet). The required upward heat flux from the floor at <u>design load conditions</u> is:

$$\text{heat flux} = \frac{\text{design load}}{\text{floor area}} = \frac{18{,}000\ \text{Btu/hr}}{1{,}800\ \text{square feet}} = 10\,\frac{\text{Btu}}{\text{hr}\bullet\text{ft}^2}$$



$$T_f = \frac{q}{2} + T_r$$

T_f = average floor surface temperature (°F)
T_r = room air temperature (°F)
q=heat flux (Btu/hr/ft^2)

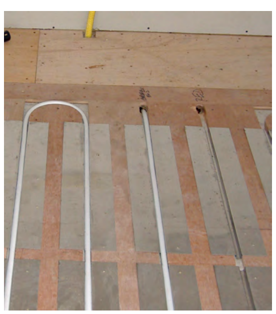
$$T_f = \frac{10}{2} + 68 = 73$$

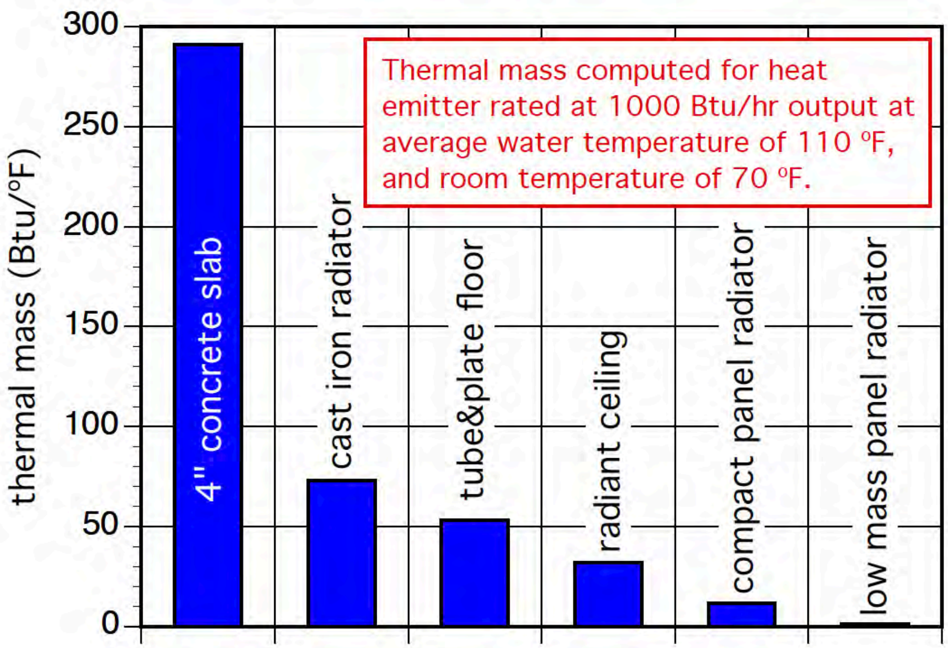
To deliver 10 Btu/hr/ft^2 the floor only has to exceed the room temperature by 5 °F. Thus, for a room at 68 °F the average floor surface temperature is only about 73 °F.

*<u>This is not going to deliver **"barefoot friendly floors"** - as so many ads for floor heating promote.</u>*

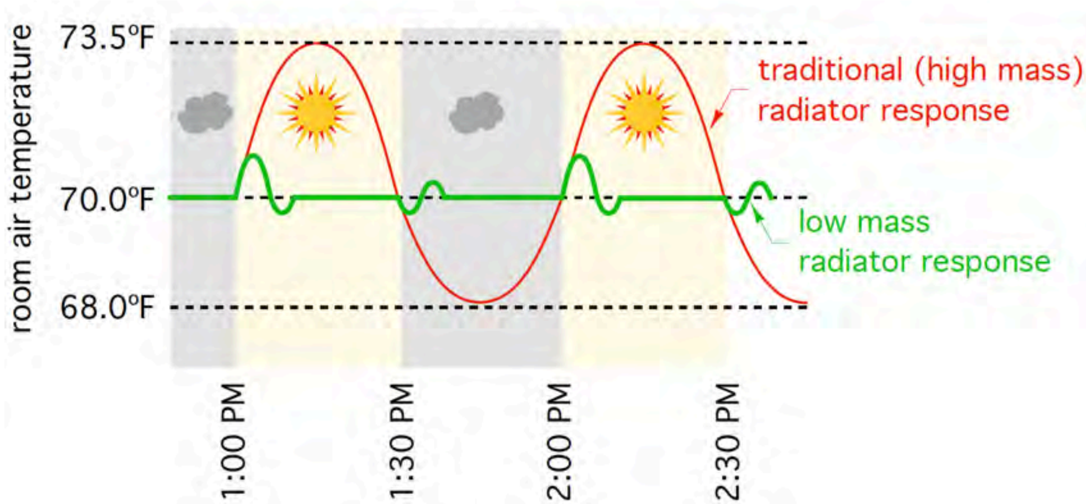
A comparison of THERMAL MASS for several heat emitters:
All heat emitters sized to provide 1000 Btu/hr at 110 ºF average water temperature, and 70 ºF room temperature:

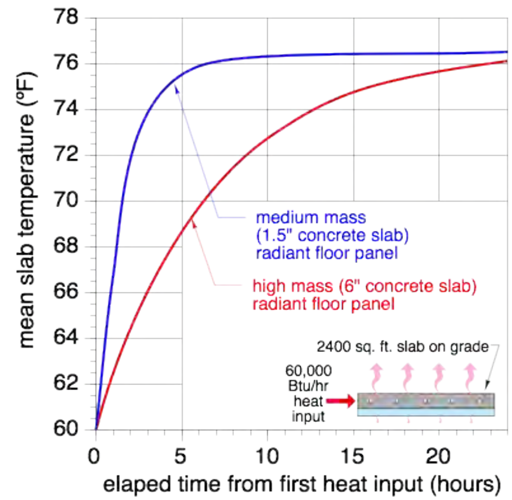
low mass heat emitters will be increasingly important in low energy buildings - especially those with significant solar heat gain.





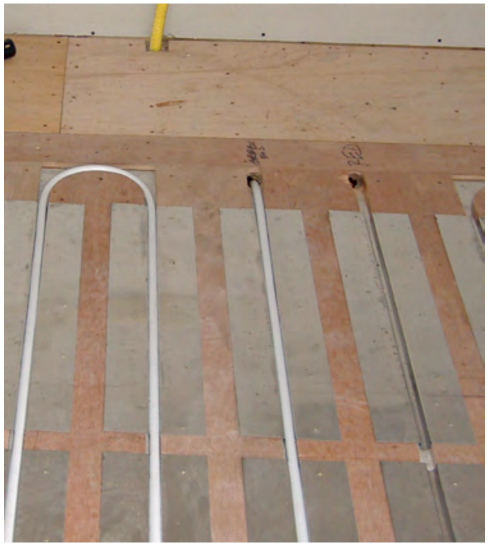
Low thermal mass allows the heat emitters to quickly respond to changing internal loads

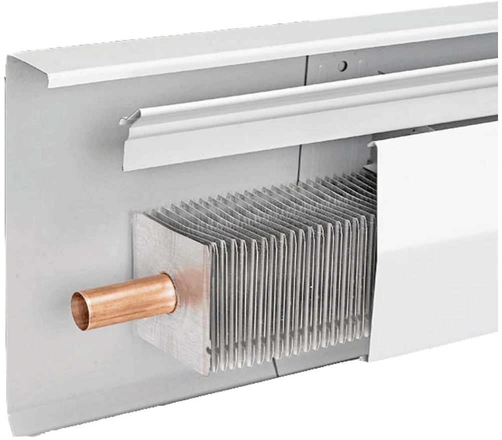




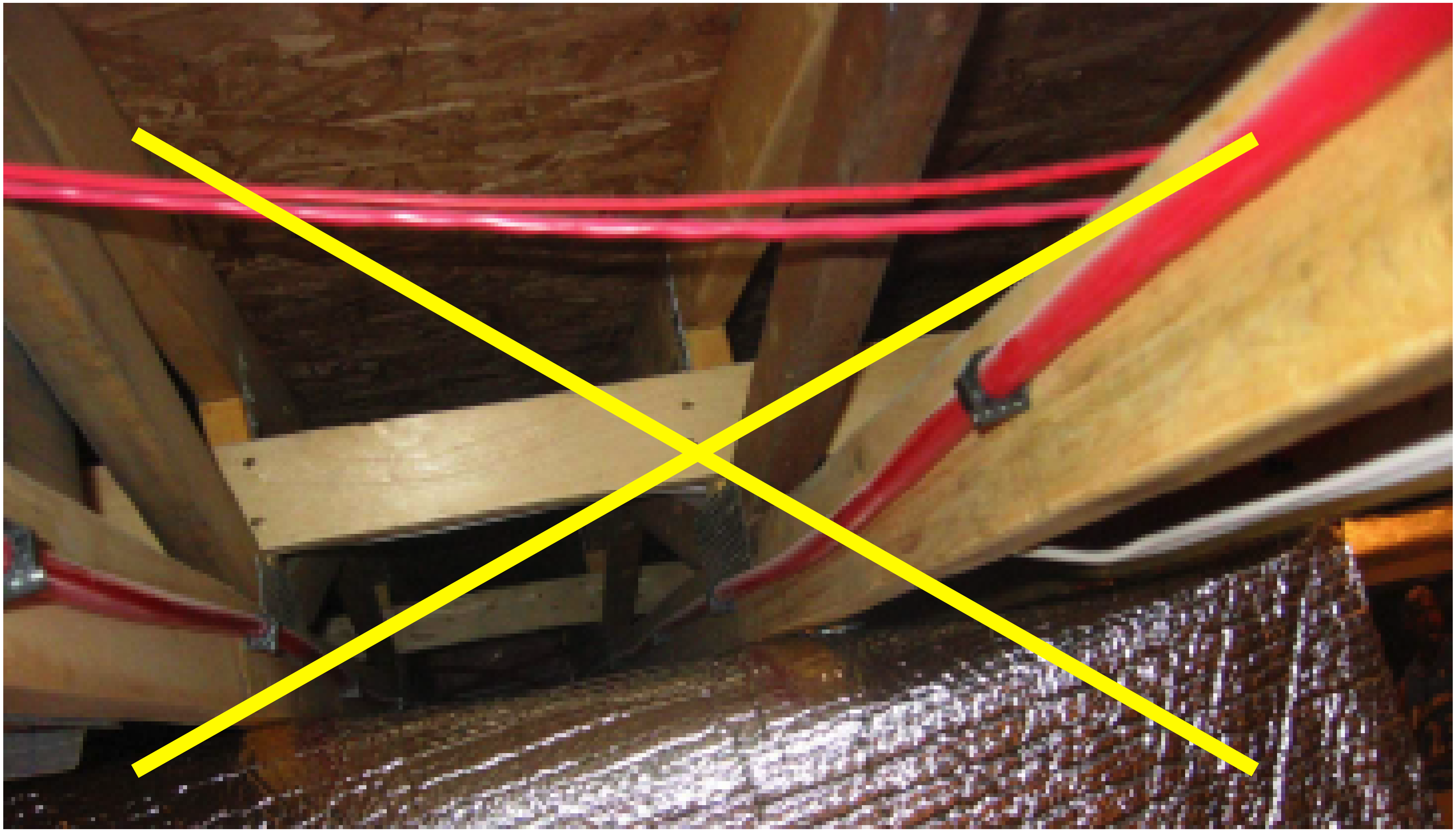
Notice where the tubing is in this 6” heated concrete slab

Low temperature hydronic heat emitter options

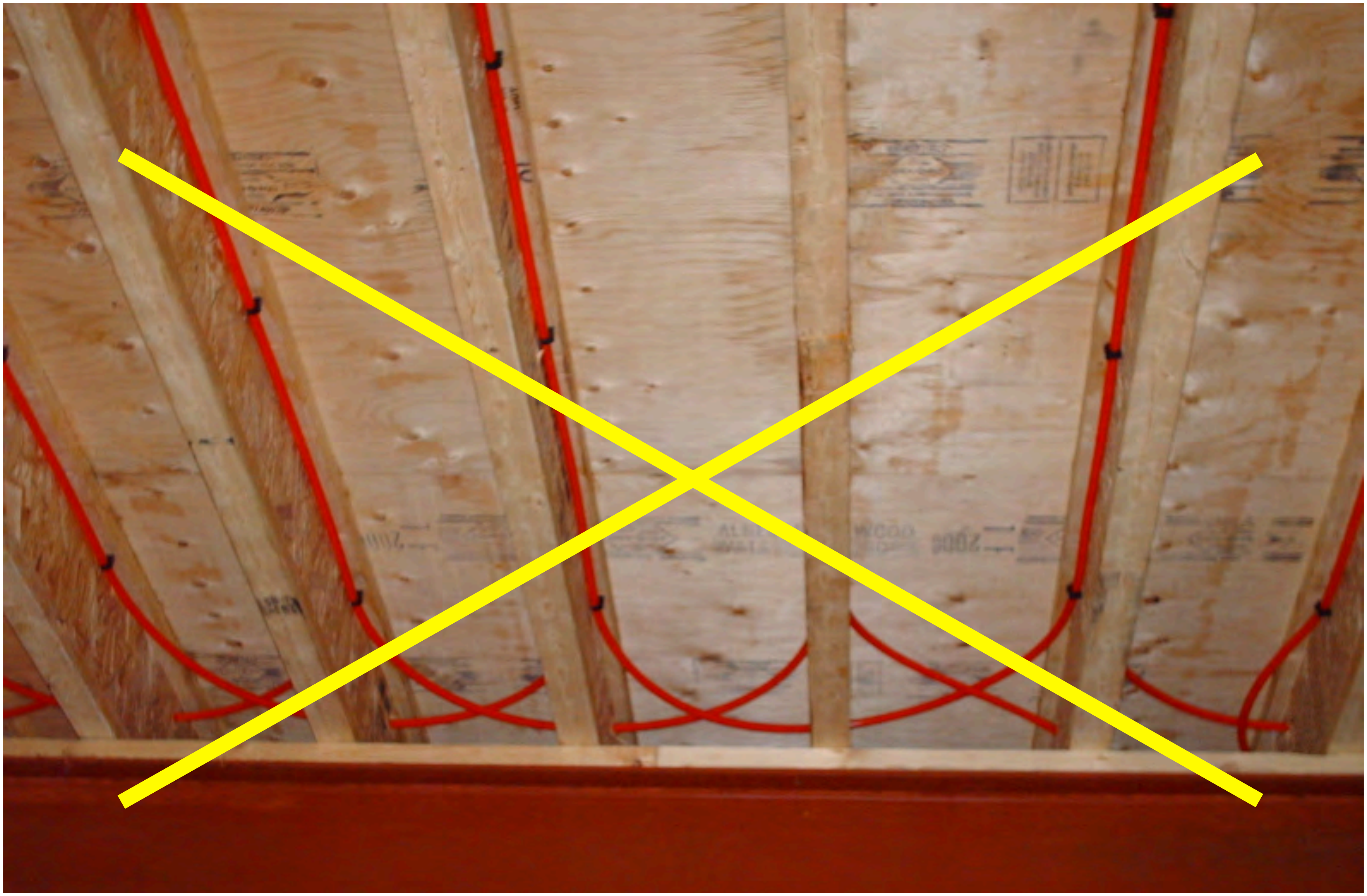



Don't do this with ANY hydronic heat source!



Heat transfer between the water and the upper floor surface is severely restricted!

Don't do this with ANY hydronic heat source!



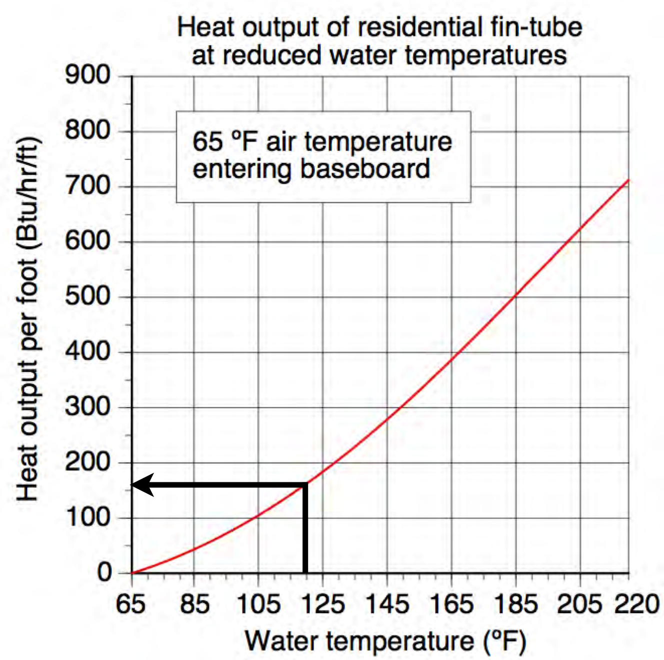
Heat transfer between the water and the upper floor surface is severely restricted!

What about standard fin-tube baseboard?

Most fin-tube baseboard has been sized around boiler temperatures of 160 to 200 °F. <u>Much too high for good thermal performance of low temperature hydronic heat sources.</u>

Could add fin-tube length based on lower water temperatures. BUT...

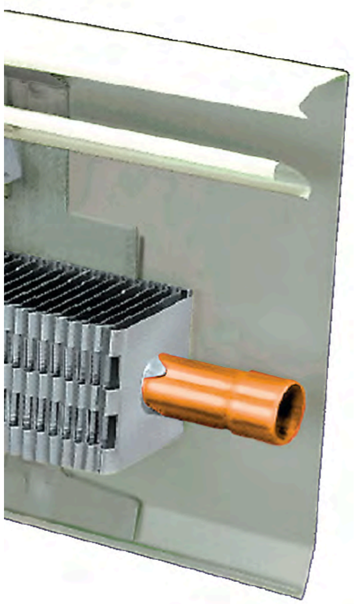
Fin-tube output at 120 °F is only about 30% of its output at 200°F (160 Btu/hr/ft @ 120 °F)



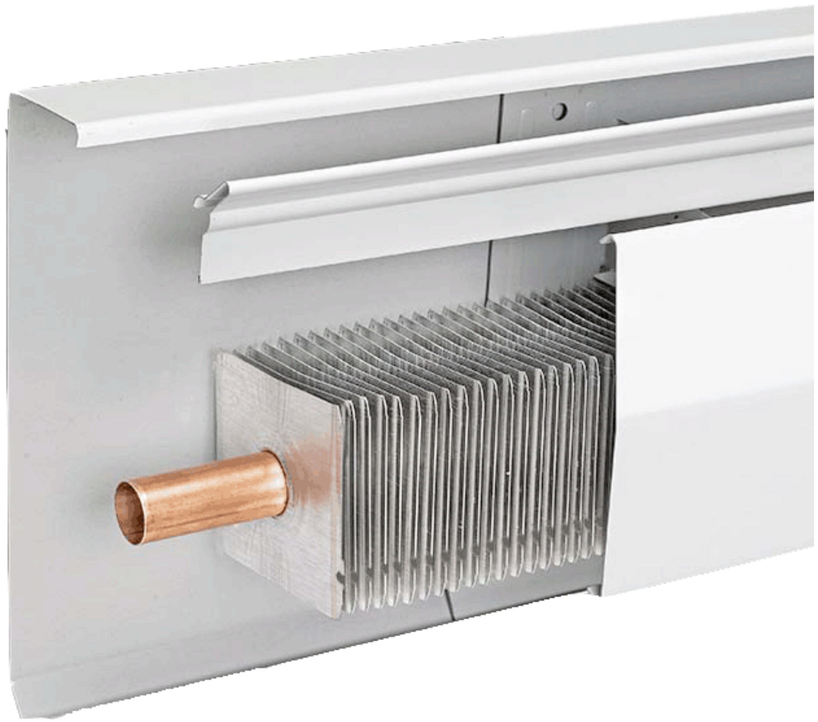
Hydronic heat emitters options for low energy use houses

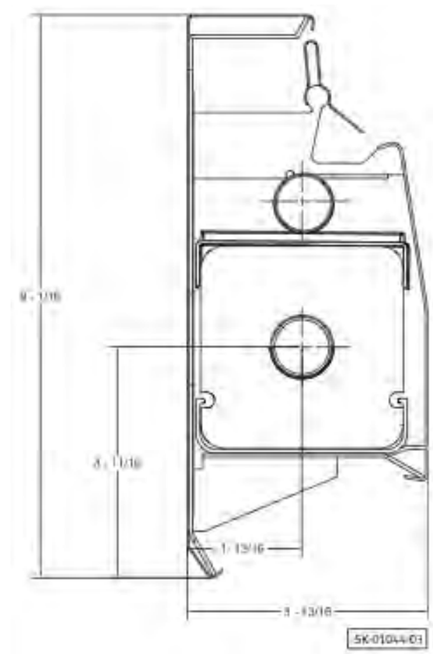
Some low- temperature baseboard is now available

Mestek Synergy baseboard



Standard residential fin-tube baseboard





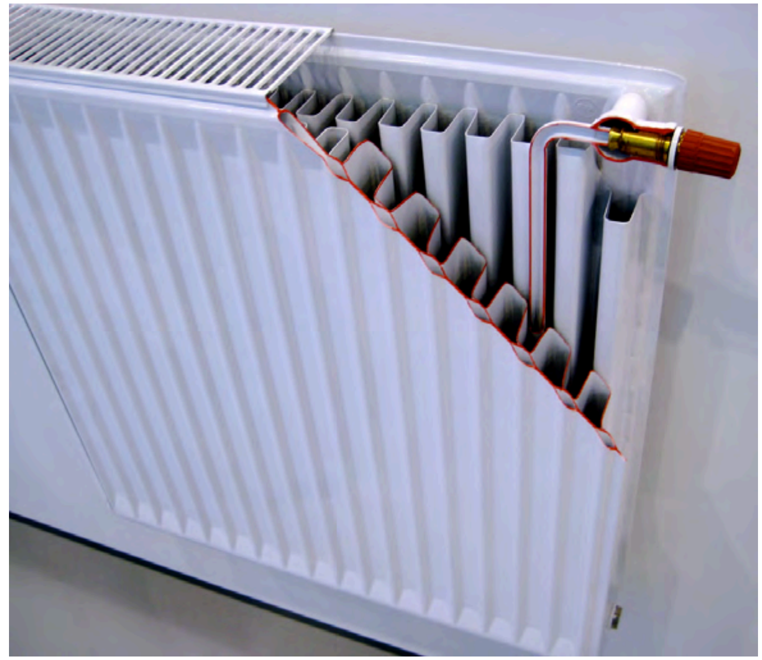
Btu/hr/ft	100 °F	110 °F	120 °F	130 °F	140 °F
1 GPM	159	232	312	390	477
4 GPM	167	245	328	411	502

These ratings include 15% heating effect factor

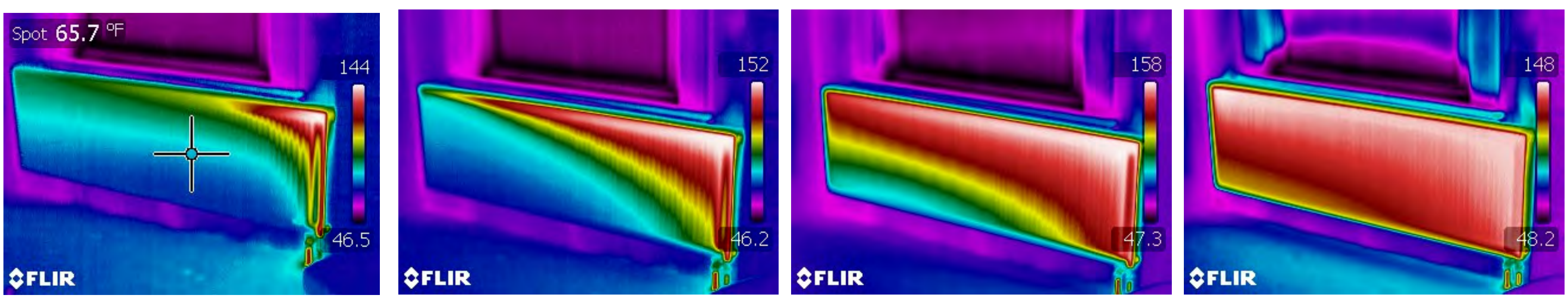
RECOMMENDATION:
Design hydronic distribution system for a supply water temperature no higher than 120 °F @ design load conditions.

Hydronic heat emitters options

Panel Radiators



One of the fastest responding hydronic heat emitters

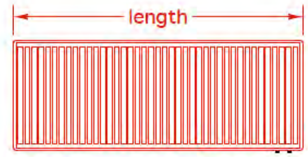


From setback to almost steady state in <u>4 minutes</u>...

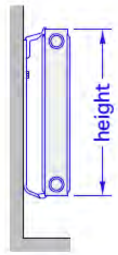
Hydronic heat emitters options for low energy use houses

Panel Radiators

- Adjust heat output for operation at lower water temperatures.

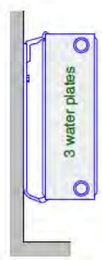


Heat output ratings (Btu/hr) at reference conditions:
Average water temperature in panel = 180°F
Room temperature = 68°F
temperature drop across panel = 20°F

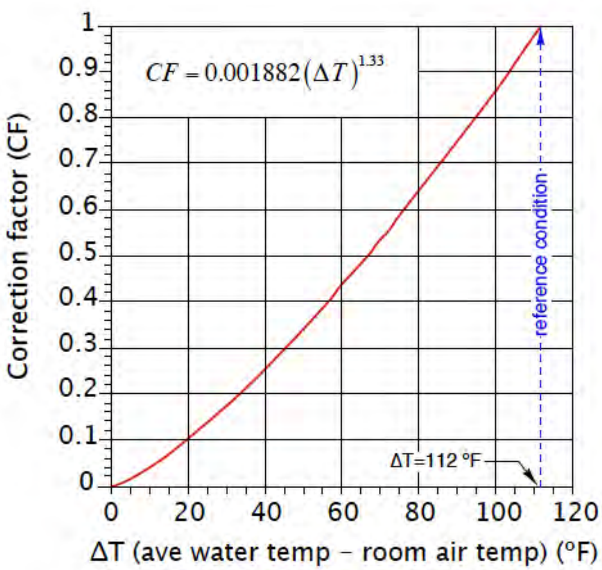


	1 water plate panel thickness					
	16" long	24" long	36" long	48" long	64" long	72" long
24" high	1870	2817	4222	5630	7509	8447
20" high	1607	2421	3632	4842	6455	7260
16" high	1352	2032	3046	4060	5415	6091

	2 water plate panel thickness					
	16" long	24" long	36" long	48" long	64" long	72" long
24" high	3153	4750	7127	9500	12668	14254
20" high	2733	4123	6186	8245	10994	12368
16" high	2301	3455	5180	6907	9212	10363
10" high	1491	2247	3373	4498	5995	6745



	3 water plate panel thickness					
	16" long	24" long	36" long	48" long	64" long	72" long
24" high	4531	6830	10247	13664	18216	20494
20" high	3934	5937	9586	11870	15829	17807
16" high	3320	4978	7469	9957	13277	14938
10" high	2191	3304	4958	6609	8811	9913

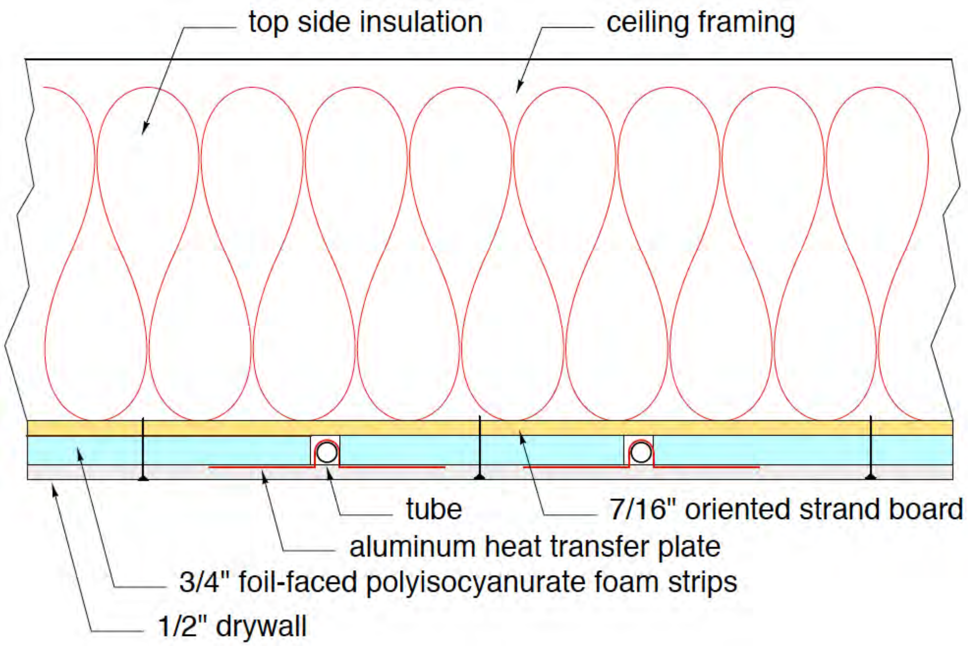


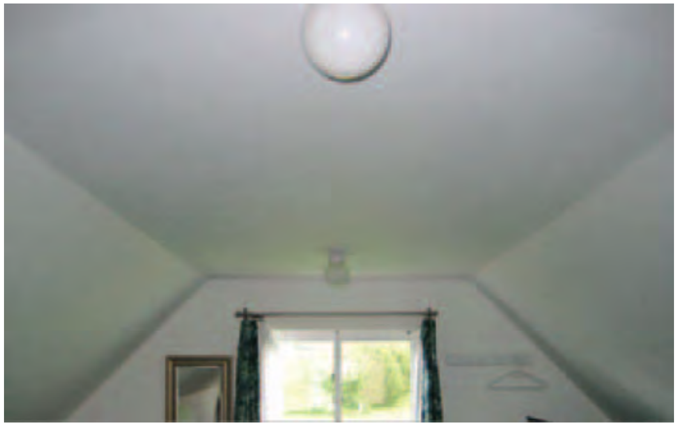
Reference condition:
Ave water temp. in panel = 180°F
Room air temperature = 68°F

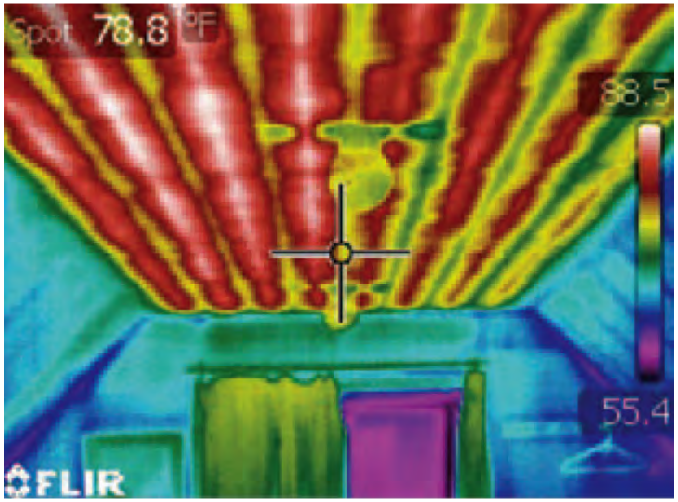
RECOMMENDATION:

Design hydronic distribution system for a supply water temperature no higher than 120 °F @ design load conditions.

Site built radiant CEILINGS...







Thermal image of radiant ceiling in operation

Heat output formula:

$$q = 0.71 \times (T_{water} - T_{room})$$

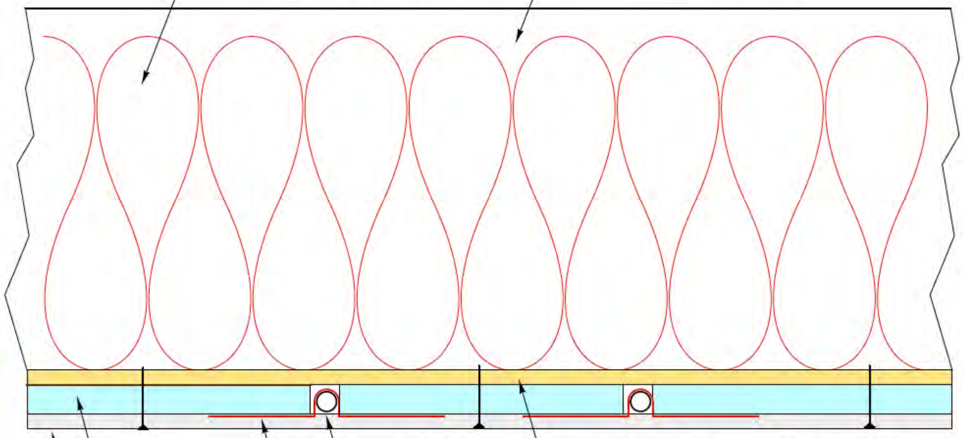
Where:

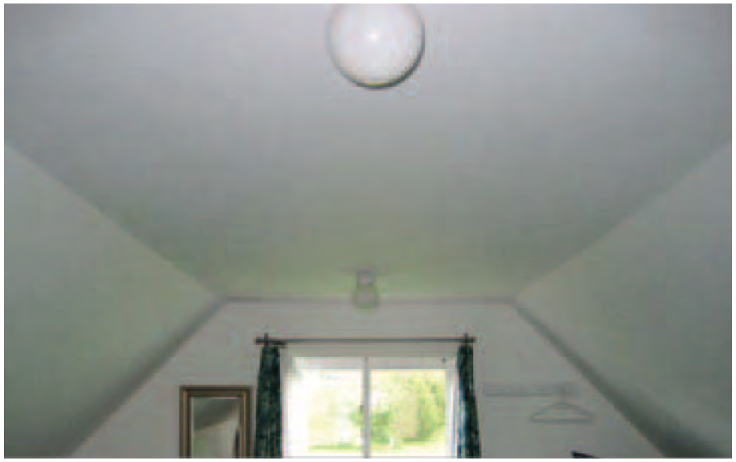
Q = heat output of ceiling (Btu/hr/ft^2)
T_{water} = average water temperature in panel (°F)
T_{room} = room air temperature (°F)

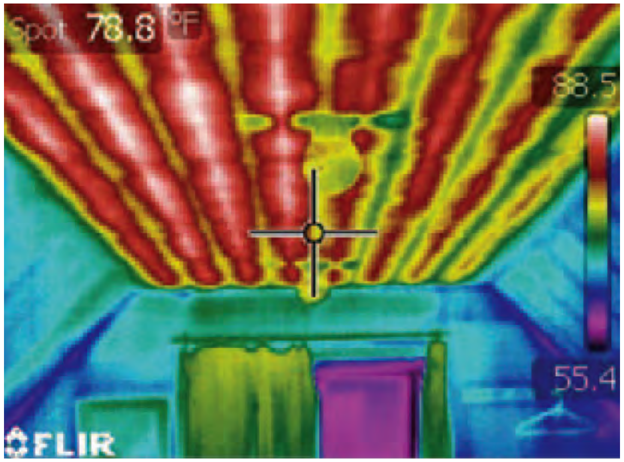
Site built radiant CEILINGS...




Site built radiant CEILINGS...

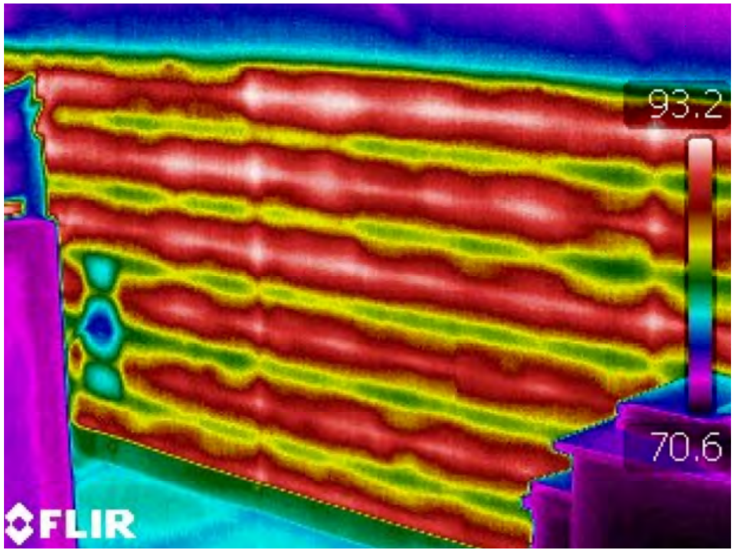


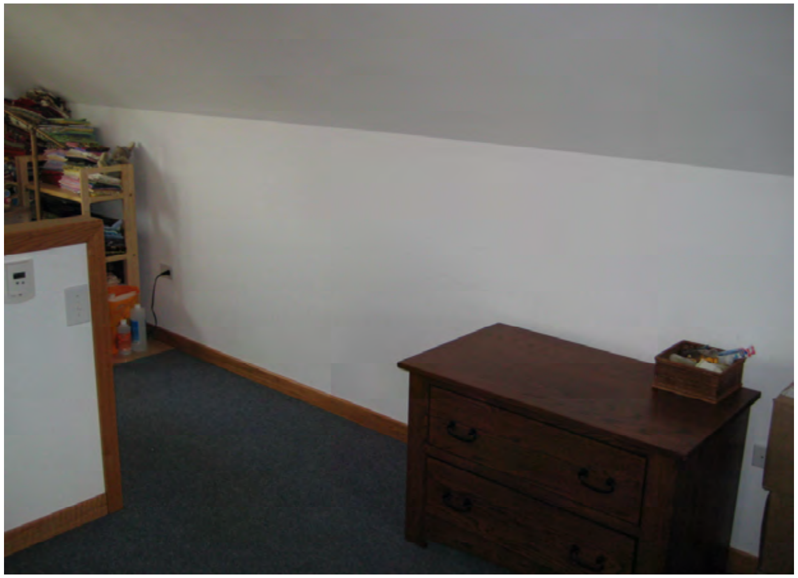




Thermal image of radiant ceiling in operation

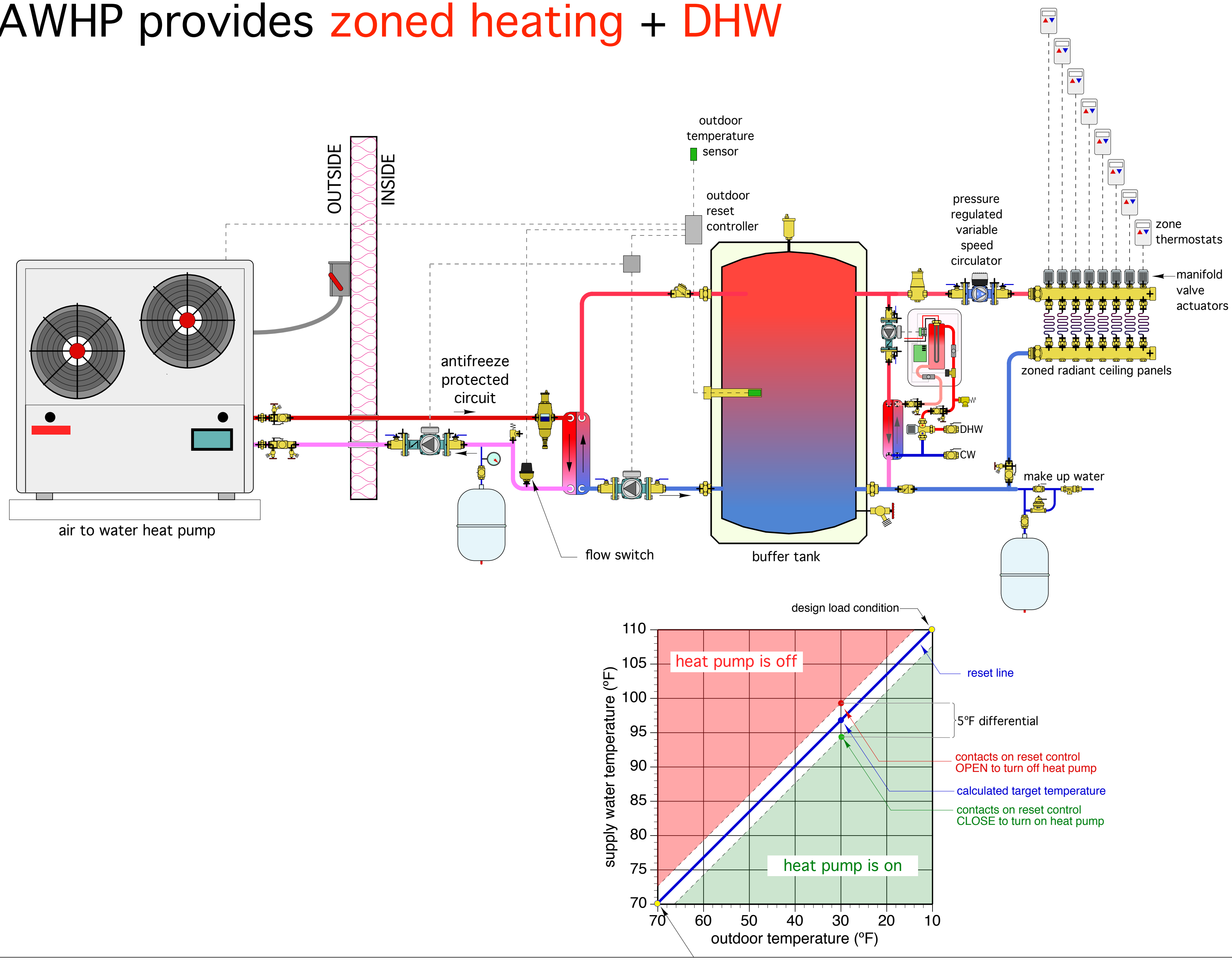
Site built radiant WALLS...



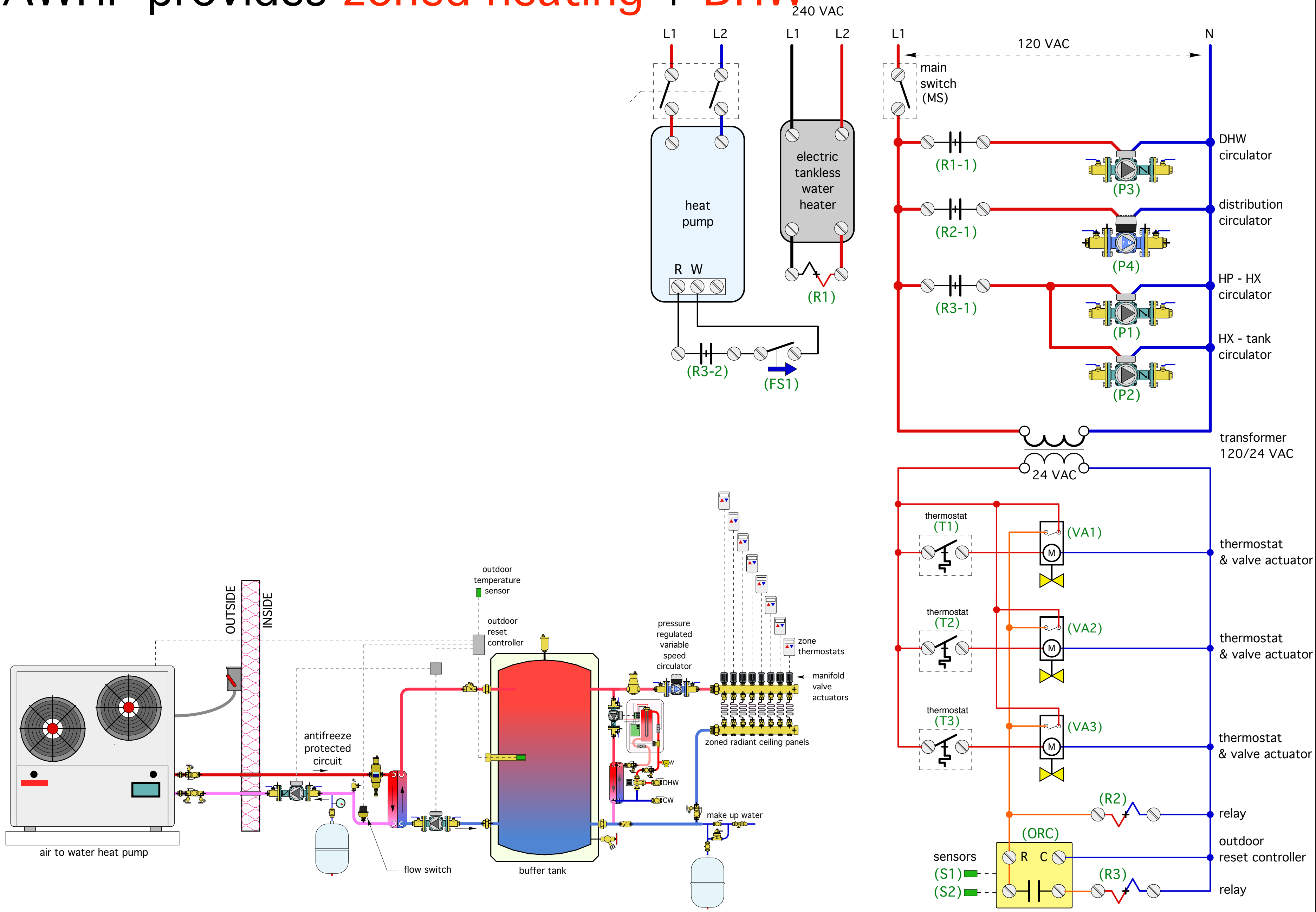


Example Systems
using
air-to-water
heat pumps

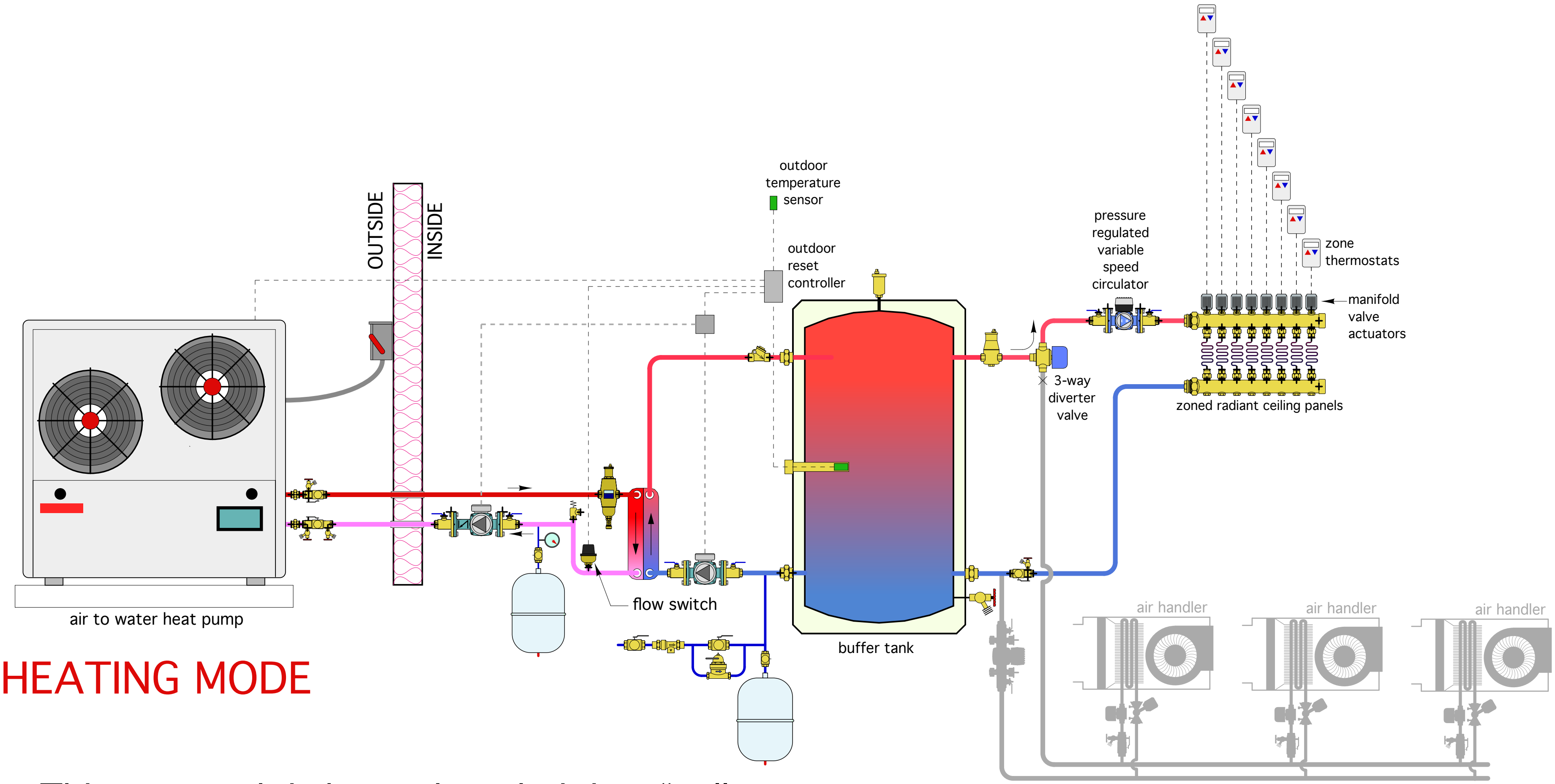
AWHP provides zoned heating + DHW



AWHP provides zoned heating + DHW



AWHP provides zoned heating + zoned cooling

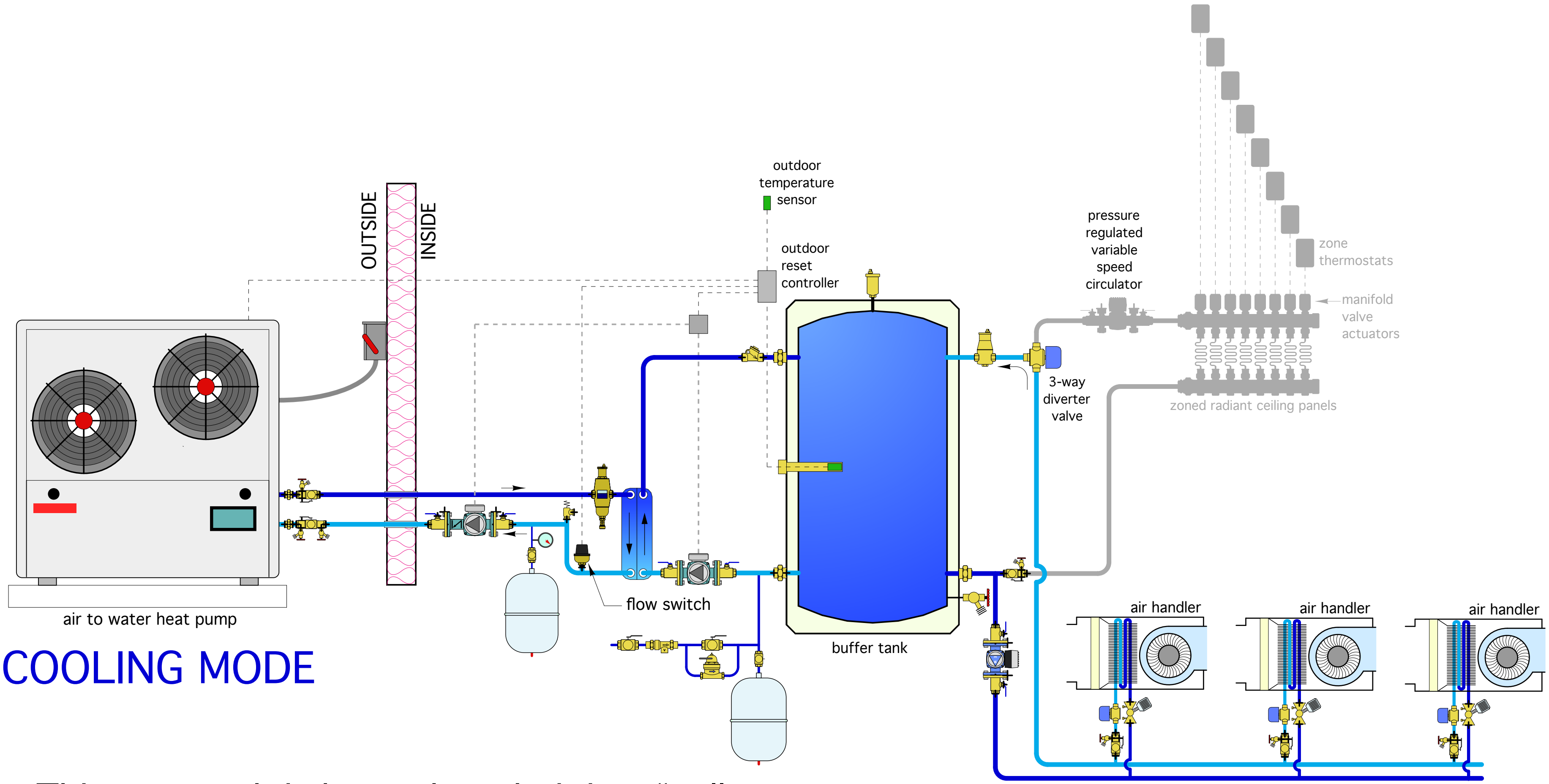


HEATING MODE

- This approach is best when their is a “null period” of several days between when heating and cooling is needed.

- All components carrying chilled water must be insulated and vapor sealed.

AWHP provides zoned heating + zoned cooling

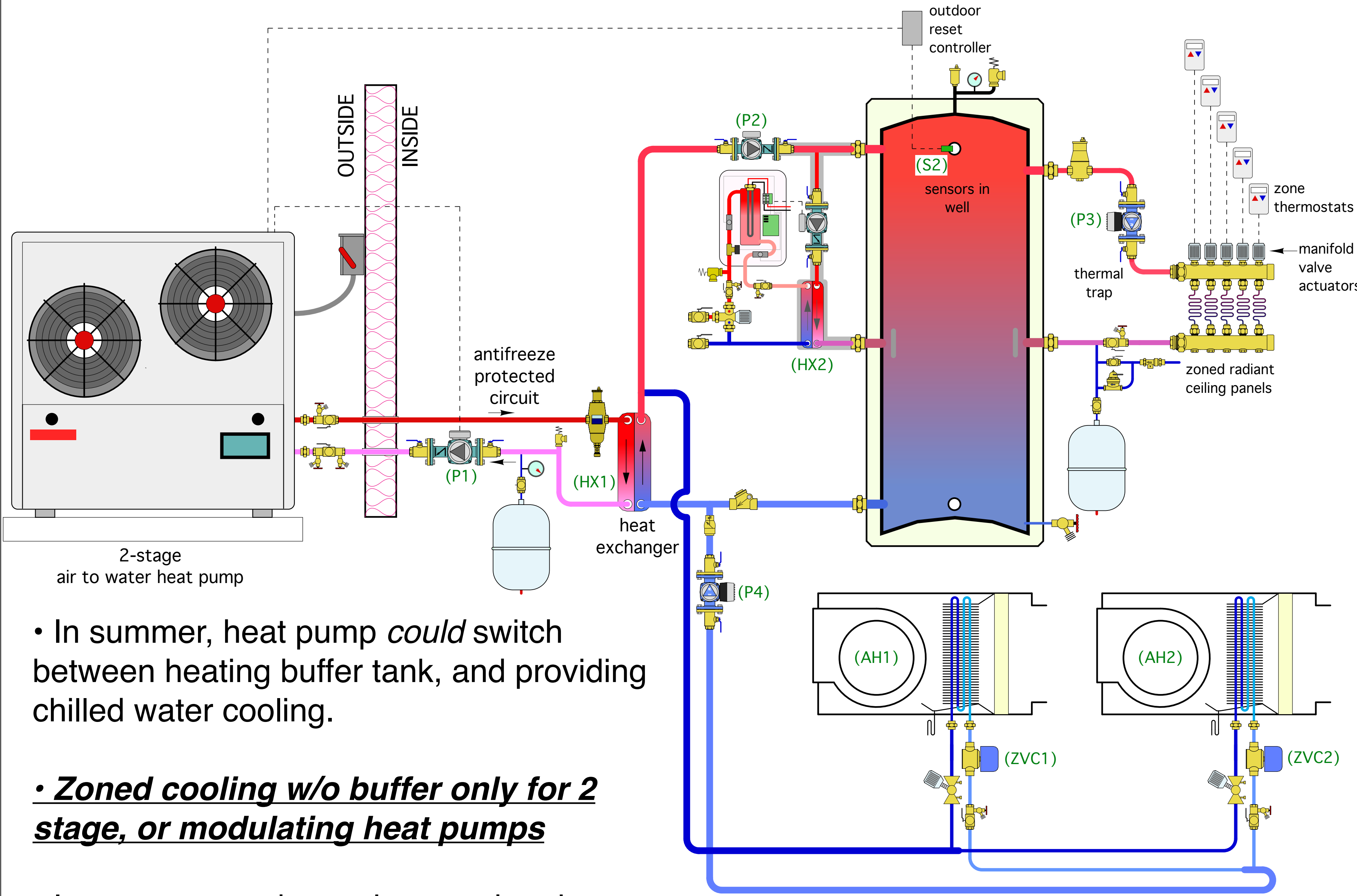


COOLING MODE

- This approach is best when their is a “null period” of several days between when heating and cooling is needed.

- All components carrying chilled water must be insulated and vapor sealed.

AWHP provides zoned heating + zoned cooling + DHW

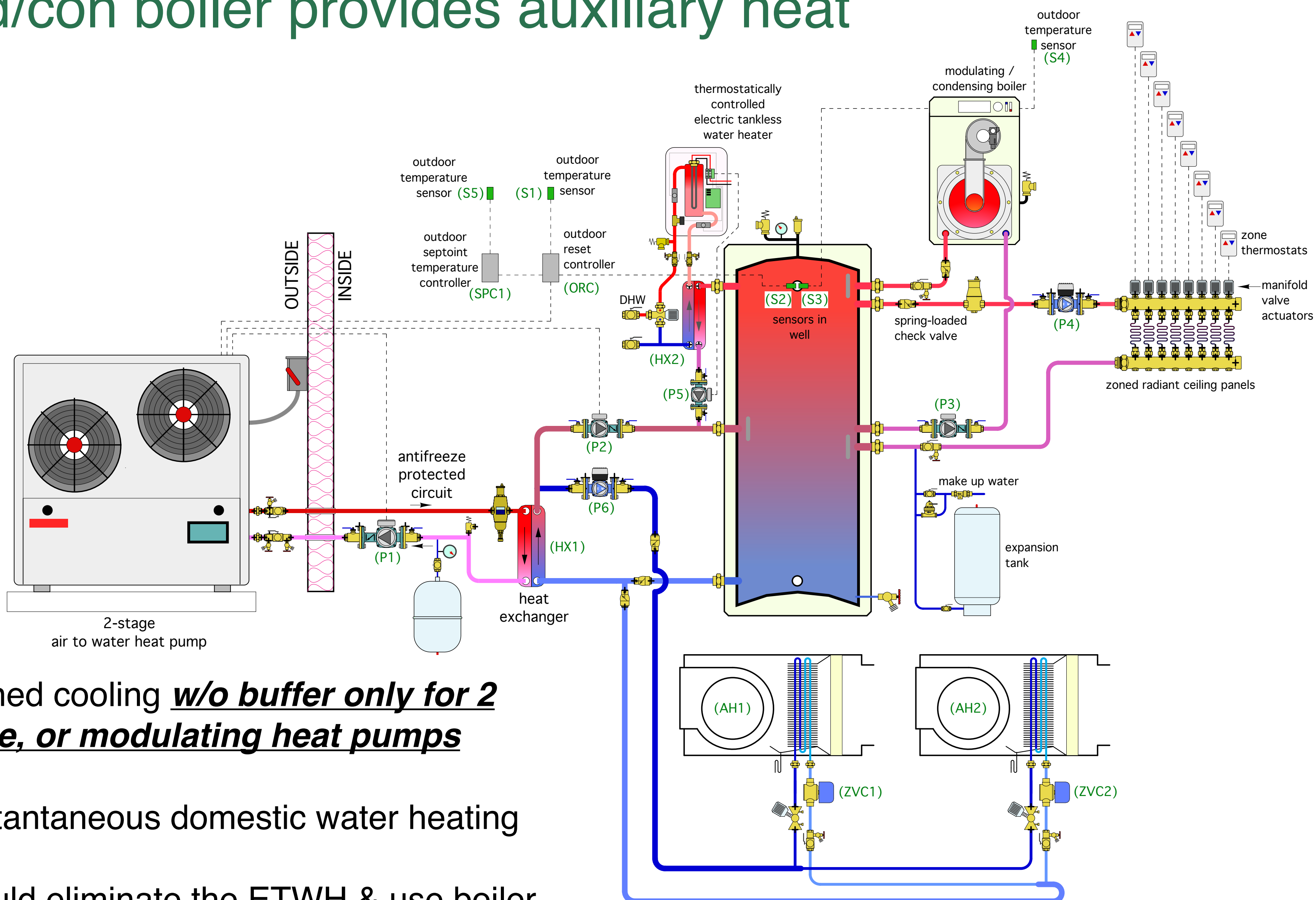


- In summer, heat pump *could* switch between heating buffer tank, and providing chilled water cooling.

<u>• Zoned cooling w/o buffer only for 2 stage, or modulating heat pumps</u>

- Instantaneous domestic water heating

AWHP provides zoned heating + zoned cooling + DHW
mod/con boiler provides auxiliary heat



• Zoned cooling ***w/o buffer only for 2 stage, or modulating heat pumps***

• Instantaneous domestic water heating

• Could eliminate the ETWH & use boiler for DHW, but at higher tank temperature.

AWHP provides excellent matching to solar PV system in net zero houses.

photo courtesy of GO Logic

• Net metering allow PV generated electricity to be “stored” by utility until needed to operate heat pump.

• Future trends are toward “all electric” houses.

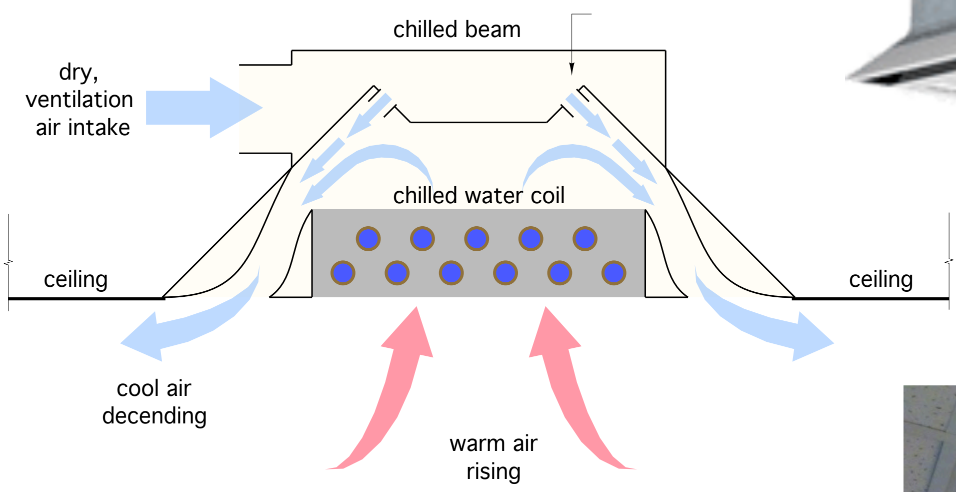
• Heating loads are so small it doesn’t pay to have gas meter

• Combine AWHP for heating, cooling, and DHW

• In California, all buildings built after 2020 will be required to be net zero.

Chilled Beams:

Active chilled Beam:



Courtesy of Dadanco

- **All chilled beams must operate above dewpoint temperature of room**

Radiant ceiling panels (for cooling)

Motivation: Move the sensible cooling load from air-side delivery to water side delivery

watts = W

watts = 0.05W

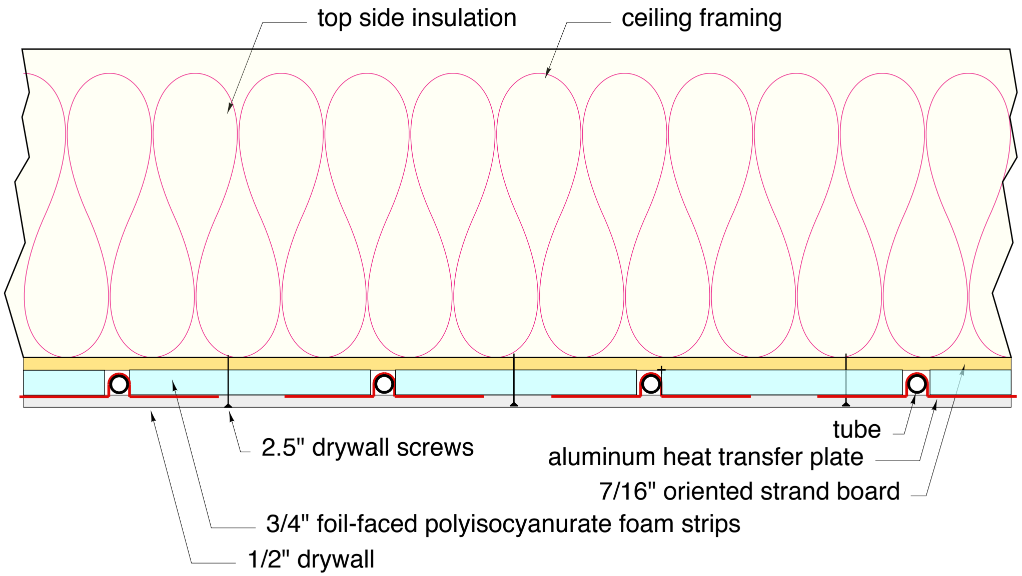
• reduces air flow requirements to those required for ventilation and latent cooling

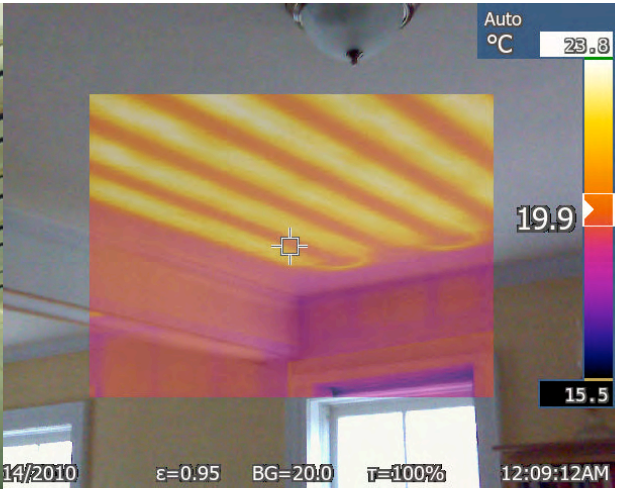
• reduces duct sizes

• reduces blower size and reduced operation cost

• reduced operating noise

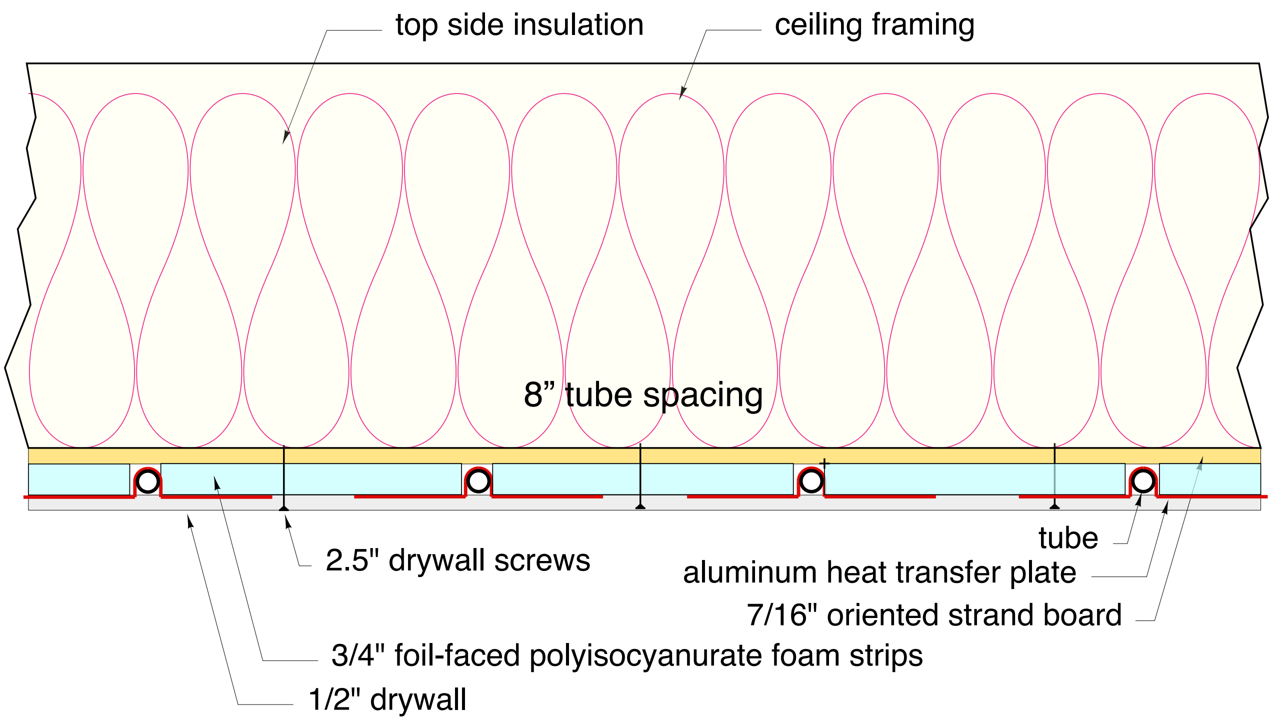
Radiant Ceiling Panels for heating & cooling





Chilled Water Cooling with Radiant Ceiling Panel

- Radiant ceilings can be used for SENSIBLE COOLING ONLY.
- Must have another air handler to handle latent load



$T_{ceiling}$ = **average** surface temperature of ceiling (°F)

T_{room} = room temperature (°F)

$q_{absorbed}$ = heat flux absorbed (Btu/hr/ft^2)

$\Delta T_{w\text{-}s}$ = difference between **average** temperature in tubing, and **average** surface temperature (°F)

$$q_{absorbed} = 1.48\left(T_{room} - \bar{T}_{ceiling}\right)^{1.1}$$

$$q_{absorbed} = 1.48(75-65)^{1.1} = 18.6\frac{Btu}{hr \cdot ft^2}$$

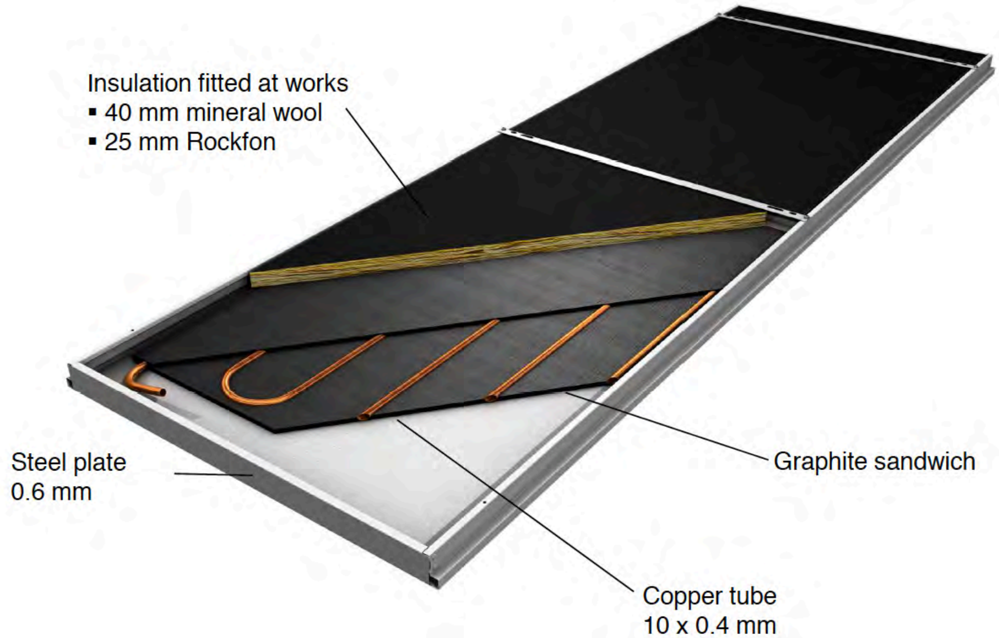
$$\Delta T_{W \to S} \cong 0.462\left(q_{absorbed}\right)$$

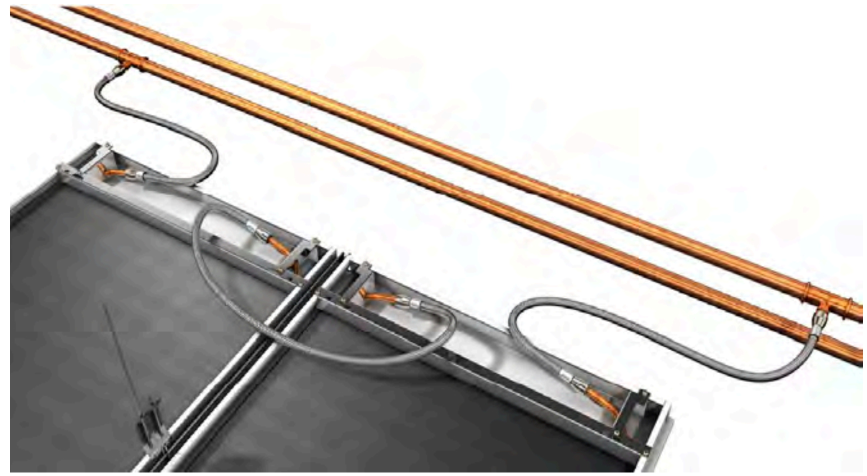
$$\Delta T_{W \to S} \cong 0.462(18.6) = 8.6^{o}\,F$$

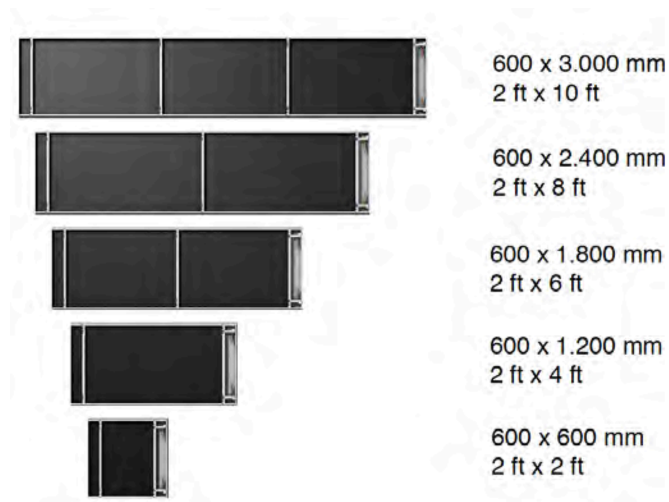
To absorb 18.6 Btu/hr/ft^2, the **average** water temperature in the tubing **of this assembly** needs to be about 8.6 ^{o}F cooler than the average surface temperature.

Suspended ceiling panels (for heating & cooling)

- low thermal mass
- fast response
- connect with “stab” fittings

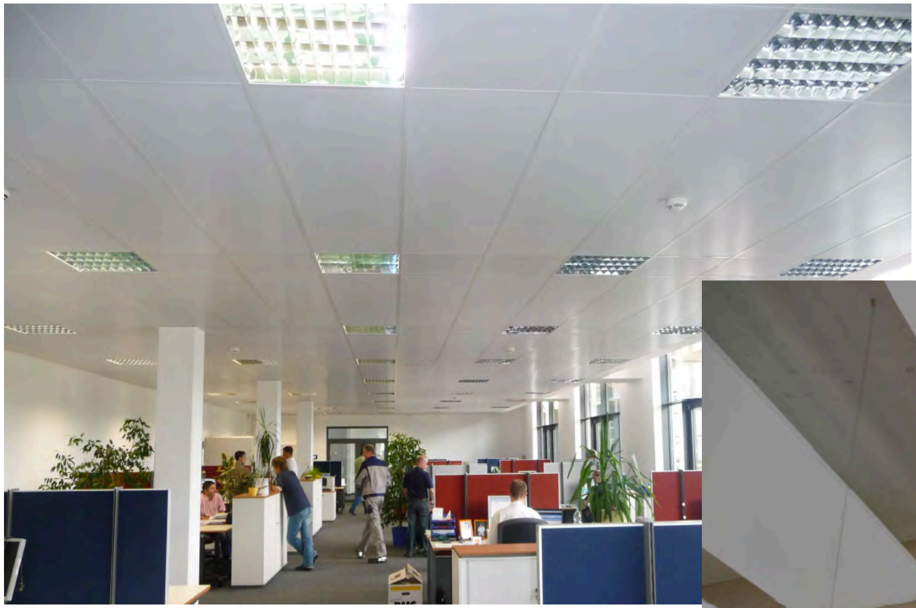






images courtesy of Zehnder

Suspended ceiling panels (for heating & cooling)



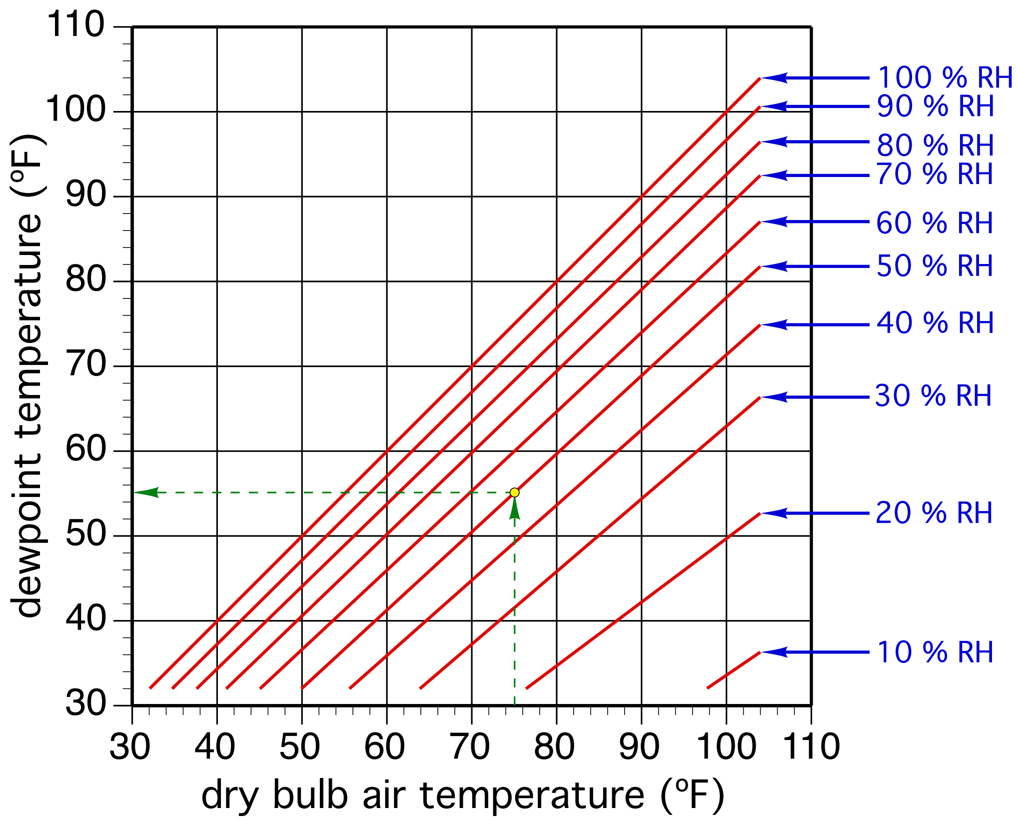
installed in T-bar ceiling

installed as self-supporting, suspended panels

images courtesy of Zehnder

Chilled Water Cooling with Radiant Ceiling Panel

Water temperature through radiant panel circuits must be maintained above dewpoint to avoid condensation.



$$T_{(^\circ C)} = \frac{T_{(^\circ F)} - 32}{1.8}$$

$$B = \frac{\ln\left(\frac{RH}{100}\right) + \left(\frac{17.27 T_{DB(^\circ C)}}{237.3 + T_{DB(^\circ C)}}\right)}{17.27}$$

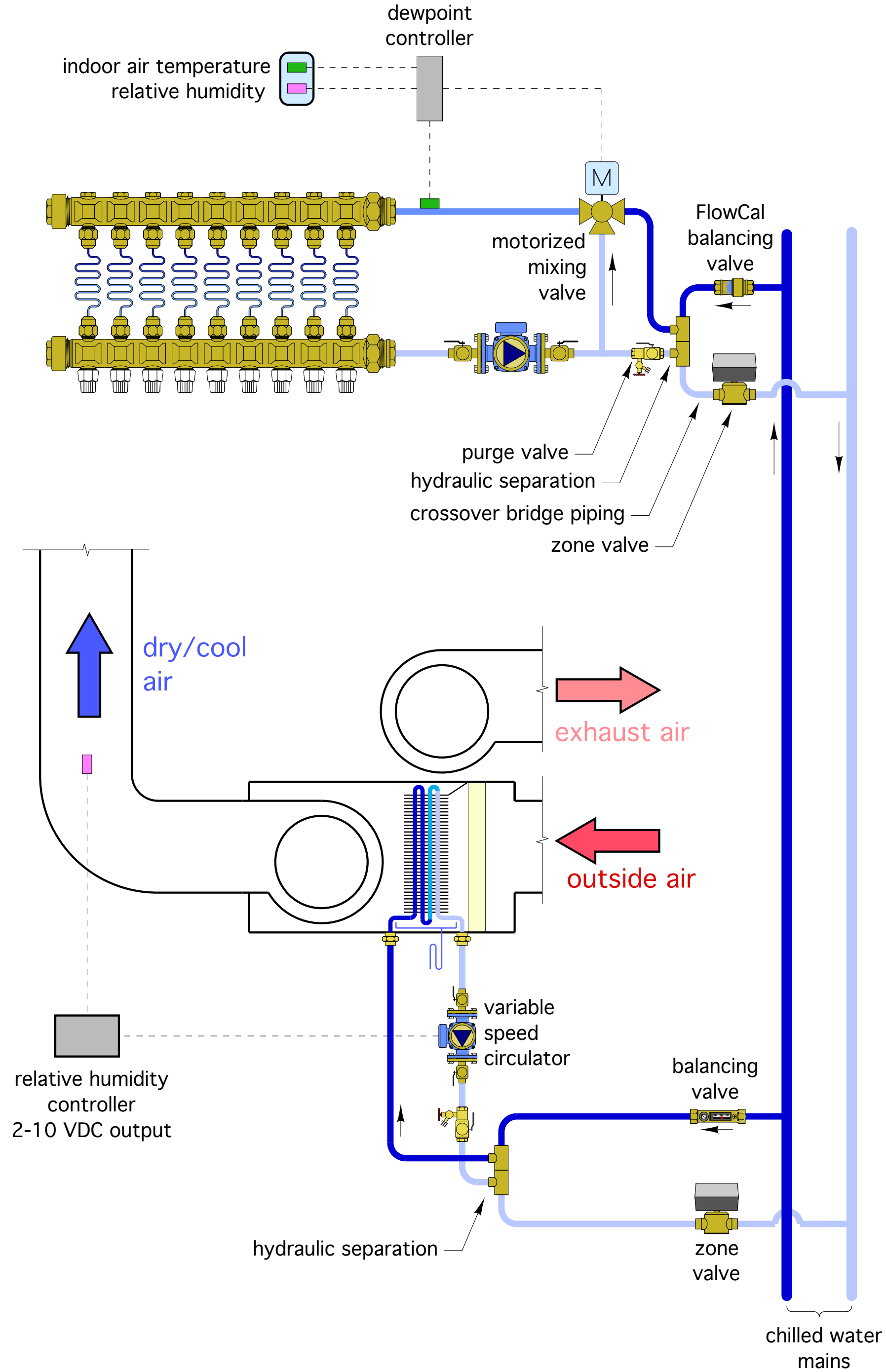
$$T_{dew(^\circ C)} = \frac{237.3B}{1-B}$$

$$T_{(^\circ F)} = 1.8 T_{(^\circ C)} + 32$$

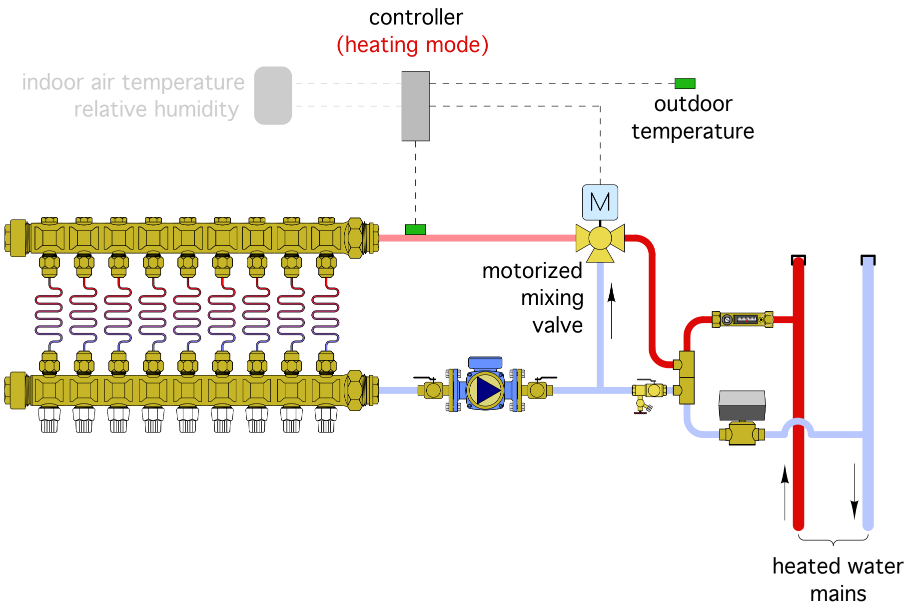
Chilled Water Cooling with Radiant Ceiling Panel

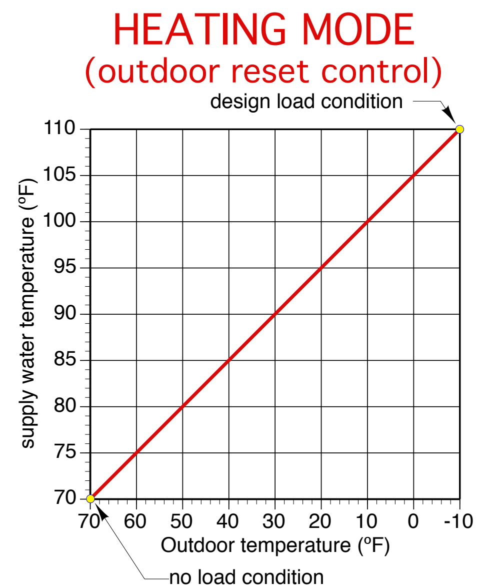
- Mixing valve operated by dewpoint controller maintain radiant panel supply temperature about 2-3 ºF above current room dewpoint temperature.

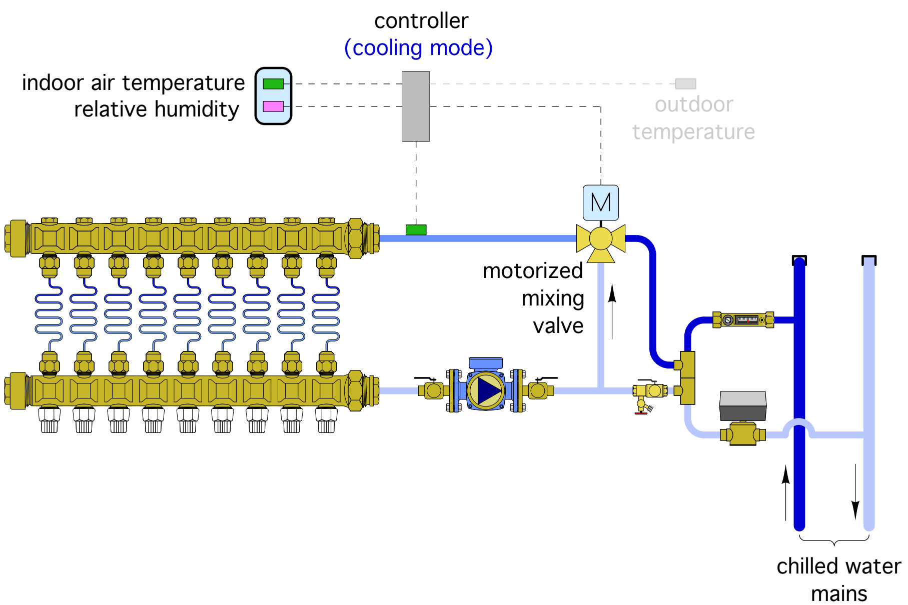
- Latent cooling and ventilation accomplished by chilled water air handler.

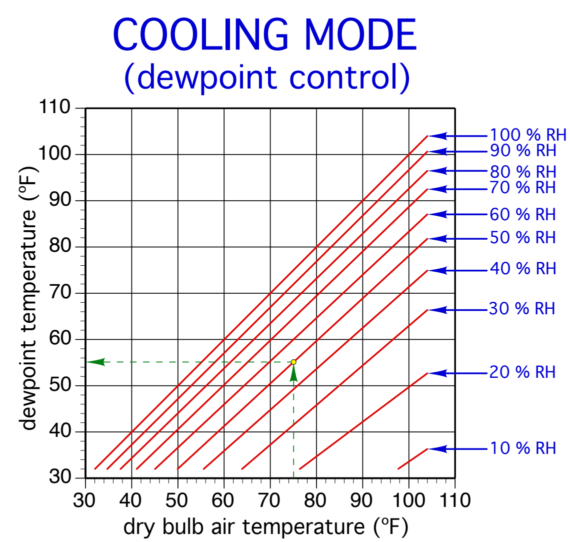


Same mixing valve and radiant panel can be used for heating, but with outdoor reset control logic (rather than dewpoint control logic).







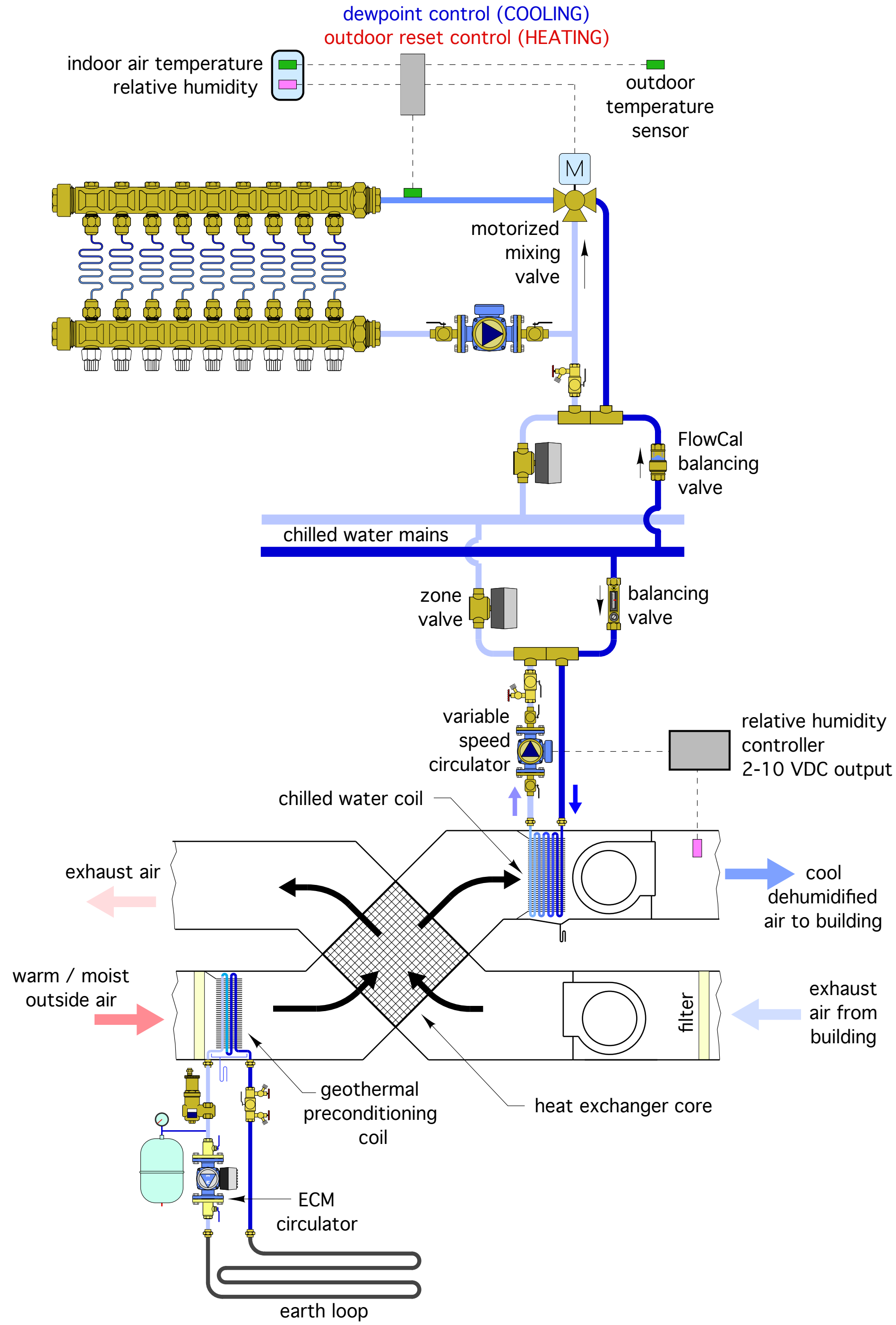


Chilled Water Cooling with HRV or ERV Ventilation

- geothermal pre-conditioning of ventilation air

- chilled water coil provide latent cooling (moisture removal)

- Radiant panel(s) provide sensible cooling



Summary:

1. Air to water heat pumps are available for hydronic heating, chilled water cooling, and domestic water heating.

2. Both “self-contained” and “split system” versions are available

3. In cold climates “self-contained” systems should use antifreeze to protect against freezing.

4. Life cycle cost can be very competitive or lower than ground source heat pumps (depending on climate and load).

5. Can be combined with large thermal storage to take advantage of favorable outdoor air temperatures and/or off-peak electrical rates.

6. Keep supply water temperature on heating distribution system as low as possible for best performance. Suggest supply water temperature at design load not exceed 120ºF.

7. Keep supply water temperature on cooling distribution system as high as possible for best performance. Suggest supply water temperature at design load not be less than 45ºF.

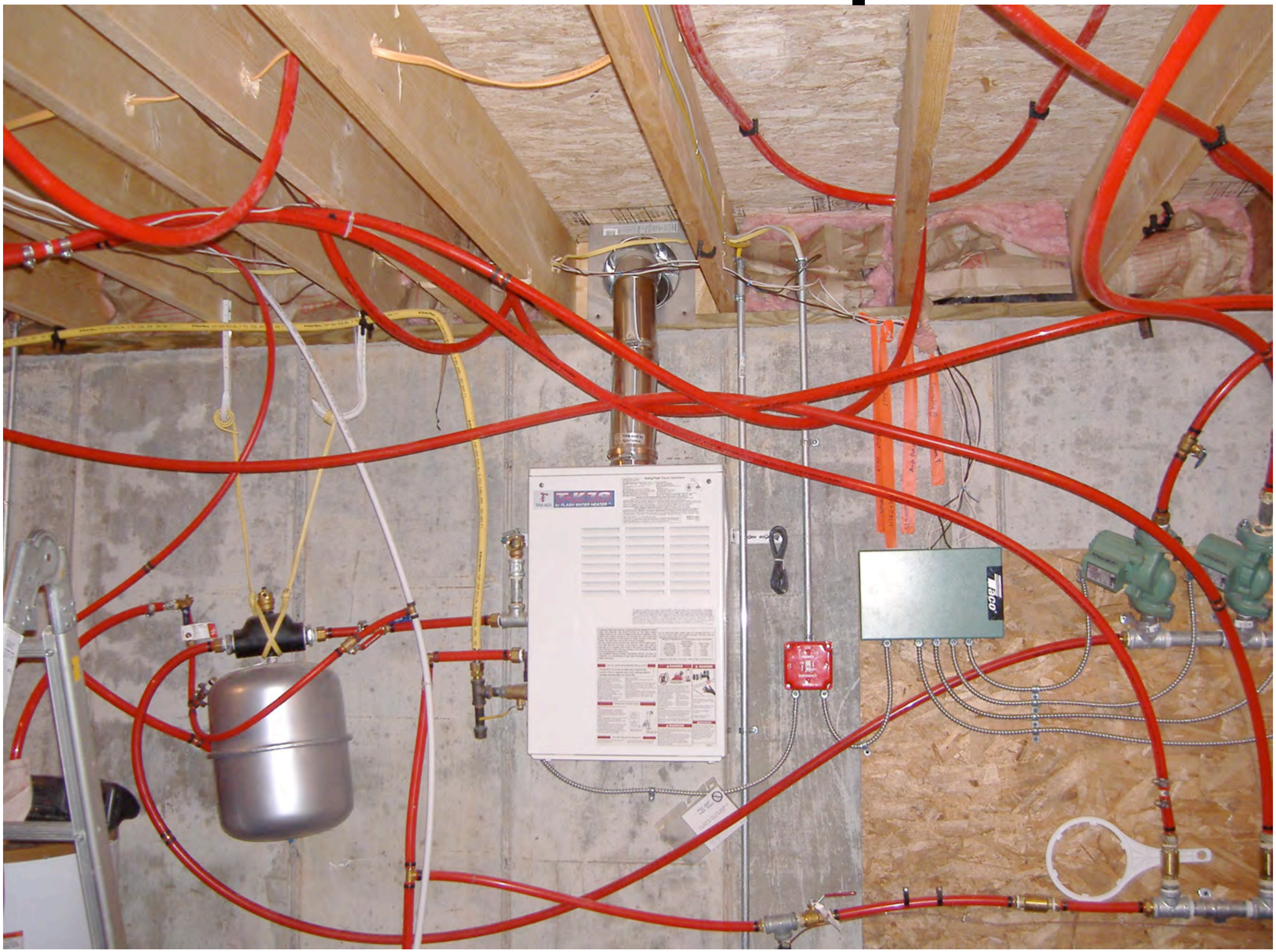
8. Use AWHPs in combination with low temperature hydronic systems, and solar PV systems in net zero and low load “all electric” buildings.

Parting thoughts...

1. Plan ahead...

Parting thoughts...

2. Keep it neat...



Parting thoughts...

3. Keep it simple...

Parting thoughts...

4. Recognize opportunity...

Thanks for attending today's session

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